NOV 1 6 1981

DOE/NE-0019

474-B

E 1.68:0019

ORIGINAL

The Monitored Retrievable Storage Concept

A Review of Its Status and Analysis of Its Impact on the Waste Management System

COMPLETED
193

U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Nuclear Waste Management and
Fuel Cycle Programs

Printed in the United States of America

Available from

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes

Printed Copy: $14.00
Microfiche Copy: $ 3.50

DOE/NE-0019

The Monitored Retrievable Storage Concept

A Review of Its Status and Analysis of Its Impact on the Waste Management System

U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Nuclear Waste Management and
Fuel Cycle Programs
Washington, D.C. 20545

CONTENTS

Page

Executive Summary

1 Introduction 1-1

2 Waste Management Systems Analysis 2-1
  2.1 Elements of the waste-management system 2-1
  2.2 Characteristics of monitored retrievable storage 2-4
  2.3 Potential roles for monitored retrievable storage 2-5
  2.4 MRS impact on the waste management system 2-13
    2.4.1 Health and safety 2-13
    2.4.2 System costs 2-15
    2.4.3 Public acceptance 2-35
    2.4.4 Impact on the waste-management facility requirements 2-37
  2.5 MRS rationale 2-39

3 Area/Location Screening 3-1
  3.1 Introduction 3-1
  3.2 Technical approach 3-1
    3.2.1 Screening process 3-2
    3.2.2 Limitations 3-2
  3.3 Screening specifications 3-3
  3.4 National screening 3-11
  3.5 Detailed screening 3-18
  3.6 Sensitivity analysis 3-18

4 Concept Screening and Evaluation 4-1
  4.1 Alternative concept descriptions 4-1
    4.1.1 Open-field dry-wells concept 4-1
    4.1.2 Surface cask concept 4-3
    4.1.3 Concrete cask-in-trench concept 4-3
    4.1.4 Air-cooled surface vault concept 4-6
    4.1.5 Closed-cycle-cooled vault concept 4-6
    4.1.6 Tunnel dry-well concept 4-9
    4.1.7 Tunnel-rack concept 4-9
  4.2 Evaluation of alternative concepts 4-12
    4.2.1 Evaluation factors 4-12
    4.2.2 Evaluation process 4-12
  4.3 Results 4-13

5 Technology 5-1
  5.1 Introduction 5-1
  5.2 Requirements for an MRS facility 5-1
    5.2.1 Functional requirements 5-1
    5.2.2 Technical requirements 5-1
  5.3 Review of technological status of MRS concepts 5-2
    5.3.1 Receiving and packaging 5-2
    5.3.2 Storage and retrieval 5-2

CONTENTS (Continued)

Page

6 Demonstration Facility Description 6-1
  6.1 Background 6-1
  6.2 Conceptual designs for the Hanford Site 6-2
    6.2.1 Siting 6-2
    6.2.2 Functional requirements 6-5
    6.2.3 General design criteria and operational requirements 6-5
    6.2.4 Demonstration facility conceptual design--open-field dry-well storage 6-7
    6.2.5 Demonstration facility conceptual design--tunnel-rack storage 6-15
    6.2.6 Capital cost estimates for Hanford 6-20
  6.3 Conceptual designs for the Nevada Test Site 6-24
    6.3.1 Siting 6-24
    6.3.2 Functional requirements 6-25
    6.3.3 General design criteria and operational requirements 6-25
    6.3.4 Demonstration facility conceptual design--open-field dry-well storage 6-27
    6.3.5 Demonstration facility conceptual design--tunnel dry-well storage 6-35
    6.3.6 Capital cost estimates for the Nevada Test Site 6-37
  6.4 Schedule 6-37

TABLES

Table	Title	Page
2-1	Cost comparison of alternative MRS concepts	2-18
2-2	Cost breakdown of alternative MRS concepts	2-19
2-3	Economic evaluation comparison of alternative MRS concepts	2-20
2-4	Summary of cost estimates	2-21
2-5	Comparative cost evaluation of the waste-management system--spent-fuel disposal	2-25
2-6	Comparative cost evaluation of the waste-management system--HLW disposal	2-26
2-7	Discounted cost comparison of the waste-management system--spent-fuel disposal	2-28
2-8	Discounted cost comparison of the waste-management system--HLW disposal	2-29
2-9	Discounted cost comparison for disposal of 50-year-old and 100-year-old spent fuel and high-level waste	2-32
3-1	Screening issues, considerations, measures, specifications, and rationale	3-4
3-2	Factors considered but not used in the screening study	3-12
3-3	Sensitivity analysis specifications	3-19
3-4	Sensitivity analysis results	3-20
6-1	Cost estimate for an MRS demonstration facility with open-field dry-well storage at Hanford	6-22
6-2	Cost estimate for an MRS demonstration facility with tunnel-rack storage at Hanford	6-23
6-3	Cost estimate for an MRS demonstration facility with open-field dry-well storage at the Nevada Test Site	6-38

TABLES (Continued)

Table	Title	Page
6-4	Cost estimate for an MRS demonstration facility with tunnel dry-well storage at the Nevada Test Site	6-40

FIGURES

Figure	Title	Page
2-1	Once-through fuel-cycle scenarios	2-9
2-2	Reprocessing fuel-cycle scenarios	2-10
2-3	Unit cost as a function of discount rate	2-30
2-4	Annual Government cost for spent-fuel disposal--1982 to 2000	2-33
2-5	Annual Government cost for HLW disposal--1982 to 2000	2-34
3-1	National screening results, MRS tunnel facility, western United States	3-13
3-2	National screening results, MRS tunnel facility, eastern United States	3-14
3-3	National screening results, MRS surface facility, western United States	3-15
3-4	National screening results, MRS surface facility, eastern United States	3-16
4-1	Open-field dry-well concept	4-2
4-2	Surface cask concept	4-4
4-3	Concrete cask-in-trench concept	4-5
4-4	Air-cooled surface vault concept	4-7
4-5	Closed-cycle vault concept	4-8
4-6	Tunnel dry-well concept	4-10
4-7	Tunnel-rack concept	4-11

FIGURES (Continued)

Figure	Title	Page
5-1	Summary of experimental test of MRS concepts	5-4
6-1	Areas of consideration for demonstration facility at Hanford	6-4
6-2	MRS demonstration facility with dry-well storage at Hanford	6-8
6-3	Dry-well encasement for Hanford	6-11
6-4	Conceptual design of waste containers for Hanford	6-13
6-5	MRS demonstration facility with tunnel-rack storage at Hanford	6-17
6-6	Schematic diagram of tunnel-rack storage	6-21
6-7	MRS demonstration facility with dry-well storage at Nevada Test Site	6-28
6-8	Dry-well encasement for Nevada Test Site	6-31
6-9	Conceptual design of waste container for Nevada Test Site	6-32
6-10	MRS demonstration facility with tunnel dry-well storage at Nevada Test Site	6-36
6-11	Generic schedule for constructing a demonstration facility	6-42

BLANK PAGE

EXECUTIVE SUMMARY

Background

The Conference Report on H.R. 7590 (House Report No. 96-1366) for the appropriations for Energy and Water Development for fiscal year 1981 directed that the U.S. Department of Energy (DOE) conduct investigations, research, and support studies for monitored retrievable repositories and prepare a site-specific report for such a repository. A more specific requirement was outlined in S. 2189 (The Nuclear Waste Policy Act--Report Together with Supplemental Views of the Senate Committee on Energy and Natural Resources, Senate Report No. 96-548, January 3, 1980), which was passed by the Senate in July 1980, but was not voted into law. This bill would have required that a study, to be delivered in 1 year, provide both a general description, cost estimates, and construction schedules for a system of monitored retrievable repositories and site-specific designs, specifications, and cost estimates for a demonstration facility with enough detail for the solicitation of construction bids.

This report has been prepared in response to the directions in House Report No. 96-1366. The scope of this study was drawn, in part, from the text of S. 2189, although the specific requirement to produce a design with enough detail for the solicitation of construction bids was not possible with the resources available or within the time of 1 year.

The concept of monitored retrievable storage (MRS) for commercial spent-fuel elements and high-level waste is based on using a high-integrity hermetically sealed canister to contain the radionuclides and a structure of some type to protect the canister from natural or man-caused events. Cooling, a necessity, is provided by a passive method (e.g., natural convection by air) to eliminate the need for the continuous operation of such machinery as water pumps or cooling fans and continuous maintenance.

Seven concepts identified for long-term storage with passive cooling are described in detail in Chapter 4. In general, the concepts considered involve the following:

1. Storage in holes drilled into the ground, referred to as "dry wells"
2. Storage in concrete structures or casks
3. Storage in tunnels that are designed to provide cooling by natural draft.

During the time that radioactive materials are stored, continuous monitoring (visual and with scientific instruments) would be conducted to prevent and minimize the release of radionuclides to the environment. The facility would provide for the retrieval of the canister of waste at any time during storage and at the end of the facility's useful life. The period of operation of an MRS facility could extend to between 100 and 300 years.

The concept of monitored retrievable storage for the long-term management of radioactive waste originated in the 1950s. Initially, the concept was applied to the indefinite storage of high-level liquid waste resulting from reprocessing. The long-term storage of such waste in steel tanks was a basis for the license given to the Nuclear Fuel Services Corporation for its reprocessing plant at West Valley, New York. In 1972, the development of a Retrievable Surface Storage Facility (RSSF) was proposed as the primary means for the storage of high-level solid waste and transuranic waste resulting from reprocessing; this would allow the development of permanent disposal facilities on a longer term basis. In 1974, the U.S. Atomic Energy Commission (AEC) issued a draft environmental impact statement on the development of the Retrievable Surface Storage Facility for review and comment. Negative reactions to this draft statement were received from a diverse group that viewed the proposed facility as only an interim measure and felt that adequate consideration had not been given to permanent disposal.

The reaction of the U.S. Environmental Protection Agency (EPA) was also negative. The Director for EPA's Office of Federal Activities stated in a letter:

> We believe that questions surrounding the management of high-level and transuranic wastes should be explored in the context of an overall waste management program that includes a vigorous effort towards ultimate waste disposal. The draft statement concentrates, to a large degree, on the facet of interim storage--covering topics such as the short-term suitability of technical containment, the Federal responsibilities for custody of radwaste, and the proper treatment of transuranium-contaminated waste. Although these topics are reasonably treated in the draft statement, the question of ultimate disposal is not.
>
> ...In light of this situation, we feel that the AEC's waste-management program, as reflected in this draft statement, has not adequately addressed the high-level waste disposal problem.

After the creation of the U.S. Energy Research and Development Administration (ERDA) in 1974, its Administrator ordered the withdrawal of the draft RSSF environmental impact statement and stated that "ERDA, in assuming responsibility for this environmental program, has taken a fresh look at the status of environmental planning and review and we have determined that the objectives of the National Environmental Policy Act would best be served by preparation of an expanded environmental impact statement before ERDA commits itself to the construction of an RSSF." The U.S. Energy

Research and Development Administration then embarked on a program dedicated to the development of geologic repositories for the permanent disposal of high-level waste.

This report is based on studies that focused on answering the following basic questions:

1. What is (are) the preferred role(s) of the MRS facility, what is its impact, and how does it compare with alternatives in the overall waste-management system?
2. Where could MRS facilities be located?
3. What would an MRS system look like and in what way and to what degree does monitored retrievable storage contribute to public health and safety? Is it licensable under existing regulations?
4. What would an MRS system cost?
5. How long would it take to implement an MRS system?
6. What concept would be selected for demonstration facilities, where could they be built, when could they be licensed and put into operation, and what would they cost to construct and operate?

Role of Monitored Retrievable Storage and Its Impacts on Cost and Facilities

The waste-management system consists of facilities and services for receiving, storing, processing, transporting, and disposing of all radioactive waste generated in the nuclear fuel cycle from mining, milling, conversion, enrichment, fuel fabrication, reactor operation, spent-fuel management, and reprocessing. Any decision about monitored retrievable storage requires the consideration of the types of waste generated from the major elements of the "back end" of the nuclear fuel cycle, namely reactors, spent-fuel storage facilities, and reprocessing facilities, as well as the requirements for the disposal of the different types of wastes. The review of requirements for waste disposal must account for the fact that spent fuel contains both resources (uranium and plutonium) and wastes (fission products and transuranic contaminants). The storage of spent fuel is considered a waste-management operation until the waste is separated from the spent fuel or the spent fuel is disposed of permanently.

A review of the description of the waste-management system and the characteristics of the MRS concept indicated that the role of monitored retrievable storage should be limited to the storage of either spent fuel or high-level waste. There are currently three different approaches to the ways the MRS system could be used. They are as follows:

1. Interim storage of spent fuel before reprocessing
2. Storage of spent fuel or high-level waste before disposal in a geologic repository
3. Indefinite storage (or disposal) of spent fuel or high-level waste

With the first approach, monitored retrievable storage would provide dry away-from-reactor (AFR) storage of spent fuel. This option was investigated in a study funded jointly by the Edison Electric Institute and the Department of Energy as a potential method for the interim storage of spent fuel until reprocessing is available. The study evaluated the requirements of facilities that would handle the storage of spent fuel that cannot be stored at reactors.

It was decided, based on an analysis of the storage shortfall, that three facilities, each with a spent-fuel capacity of 10,000 metric tons of heavy metal (MTHM), could be built as a private venture. It was estimated that 6 years would be required to design, license, and build the first facility after the selection of a site. For the analysis, site selection was assumed to occur in 1982, which means that the facility would be operational in 1988. The date for the first facility could be met if an uncontested site was immediately available, a consortium or partnership could be established to manage the project, no unusual difficulties were experienced in an untested licensing procedure, and the required funds could be raised by private entities.

Two types of facilities were considered, one based on open-field dry wells and the second on dry wells in tunnels. The estimated cost for a 10,000-MTHM facility of each type was $340 million and $992 million, respectively. The estimated storage fee was $160 per kilogram of heavy metal (kgHM) for the open-field dry-well concept and $340/kgHM for the dry well in tunnels concept.

If all the conditions identified above were satisfied and the operation date of 1988 were achieved, it might be possible to keep all nuclear reactors in operation. This would put heavy reliance on the use of the storage pool in Morris, Illinois, and possibly demands on the Barnwell, South Carolina, facility for the storage of the overflow before 1988.

If the MRS facility were delayed until 1990, there would be a shortfall of storage capacity for spent fuel of between 860 and 2500 MTHM. Approximately 740 MTHM could be stored at Morris, Illinois. With this situation, up to 17 reactors might have difficulties in continued operation.

If no action is taken to provide centralized storage, the additional at-reactor pool storage that would have to be built could require a 37,000-MTHM capacity at a cost of approximately \$7.6 billion. Using the existing facilities at Morris and Barnwell and adding more AFR capacity could reduce the investment to \$2.7 billion. This estimate assumes that some action, disposal or reprocessing, would be taken in the year 2000. Using the MRS system for interim storage which would become operational in 1990, 1993, and 1996, would keep the investment to \$3.9 billion with power plants having to expand storage capacity by 3200 MTHM.

It is currently estimated that an MRS facility built by the Federal Government could take from 9 to 11 years to complete. Therefore, if work started immediately, a facility would not be available until about 1992.

The second approach envisioned for monitored retrievable storage provides long-term storage of spent fuel or high-level waste for a period up to 100 years to allow the thermal power output to decrease before disposal by emplacement in a geologic repository. The thermal power output of average spent fuel in a once-through fuel cycle is about 1.2 kW/MTHM at 10 years out of the reactor and 0.3 kW/MTHM at 100 years. For high-level waste from a light-water reactor uranium-plutonium recycle, the power level is 2.3 kW/MTHM at 10 years and 0.2 kW/MTHM at 100 years.

For high-level solid waste in a salt repository, it is estimated that 81 MTHM/acre could be disposed of at 10 years out of the reactor, 100 MTHM/acre at 50 years, and 120 MTHM/acre at 100 years. If the repository were in granite or basalt, it could accommodate 103 MTHM/acre at 10 years, 223 MTHM/acre at 50 years, and 370 MTHM/acre at 100 years. These improvements in disposal space efficiency could result in about a 40 percent reduction in the cost of repositories. However, because of the additional cost of interim storage facilities and research and development the total cost of a 100-year delay would be approximately 20 percent greater than the current program. This figure represents a lower limit of the total cost increase because it has no provision for the cost of long-term interim storage of transuranic-contaminated waste produced during reprocessing.

The analysis of the cost on a discounted basis using a 3 percent discount rate provides a different perspective on the relative cost of the alternatives. On a \$/kgHM basis for the disposal of spent fuel, the analysis shows that a 50-year delay would mean a cost reduction of 33 percent, and a 100-year delay could reduce costs by 45 percent. For the disposal of high-level waste, a 50-year delay would mean a 21 percent savings, and a 100-year delay would mean a 35 percent savings. Discounted cost analyses show savings of 21 to 45 percent by deferring action. This apparent savings is primarily attributable to the time value of money. For the same deferral period, an analysis of the undiscounted cost shows an increase of 20 to 50 percent. The discounted cost reflects the time of the outlay, thus weighing more heavily those costs incurred early than those incurred later. This characteristic explains the apparent lower costs for those proposals that defer costs until later years.

The third approach considered the MRS facility to be the permanent method for disposal. This approach would replace a totally passive disposal method of a geologic repository with one that assumes an active management role by man to maintain and replace the facilities in perpetuity. One advantage of this approach might be that the integrity of the containment would always be known. Disadvantages would be the commitment that must be made to maintain the disposal operation, the uncertainty in the level of institutional control that would be provided in distant future years, and the unknown long-term safety of the method in the context of natural and man-caused events since the waste is still within man's environment.

On a discounted basis, the cost of this approach appears to be the lowest. When considered on an undiscounted basis no total cost can be described because of the required cost of maintenance in perpetuity.

Licensability and Protection of Health and Safety

Based on a review of the available design information for various MRS concepts, no major impact on public health and safety would be experienced by incorporating monitored retrievable storage into the waste-management system. In addition, no technical reason has been identified that would prevent an MRS concept from being licensed under current regulatory practices, although the question of a 100-year license would need to be addressed. Therefore, it appears that monitored retrievable storage could provide a long-term storage capability at a level of safety comparable to that now judged acceptable for the nuclear waste-management system.

The above conclusion is drawn from a qualitative comparison of the technologies and design approaches used in the MRS concepts compared to those now in use, or proposed for use, in spent-fuel storage in water basins.

A quantitative assessment of risk to the public health and safety (including occupational risk) would require an analysis of detailed designs under assumed normal and off-normal situations. Such an analysis was not performed during the course of this study but would have to be included as an important item of information before a final decision could be made to proceed with this concept as an integral part of the waste-management system.

Public Acceptance of the MRS System

Because the concept of monitored retrievable storage has not been previously described in any detail to the U.S. Nuclear Regulatory Commission, the Congress, or the general public, very little direct evidence of public reaction is available. However, previous experience with similar proposals in the area of nuclear waste does provide insight into what reaction might be expected.

There will probably have to be some type of incentive to encourage state and local governments to accept either a permanent repository or a long-term storage facility within their boundaries. The perceived disadvantages of either an MRS system or a permanent repository have the following common elements:

1. Concern about radioactive material.
2. The concentration of waste from Federal nuclear activities into a small number of locations raising questions about equity.
3. The transportation of radioactive material on public highways and railroads.
4. The impact on family and children; even 100 years would extend to great-great-grandchildren.

It appears that required mitigating activities for either geologic repositories or long-term MRS repositories will be very similar, if not identical.

It has been shown that deliberate interim storage for periods of 100 years would reduce the thermal load on a geologic repository and, therefore, the temperatures that will be experienced. However, apart from the intuitive feeling that lowering temperatures would be better and the generally recognized fact that chemical and physical reactions probably proceed more slowly at lower temperatures, no definite impact on the total safety of the system has been shown.

Even if a quantifiable improvement in the calculated risk from the facility were to be identified, greater public confidence would not necessarily follow. The series of reactor-cooling experiments conducted by the U.S. Nuclear Regulatory Commission in the LOFT reactor have clearly demonstrated large margins of safety in emergency core-cooling systems, and yet no appreciable change in public concerns about the safety of nuclear reactors seems to have taken place.

Public concerns about the safety of nuclear facilities have not been influenced significantly by technical information. Although this situation may be attributable to incomplete dissemination of information to the public, if this continues to be true, a new technical option for waste management, such as monitored retrievable storage, will not contribute to public acceptance even if it were to add to safety.

Locating a Site for an MRS Facility

It has been proposed that because of the temporary nature of monitored retrievable storage and the requirement that the package be totally under the control of man, an MRS facility could be located in almost any state in the continental United States. To test this hypothesis, an effort was made to develop a set of general screening criteria to identify those areas that have favorable characteristics for such a facility. The criteria developed focused on those characteristics important to maintaining containment and the known licensing requirements for surface facilities established by the U.S. Nuclear Regulatory Commission. Criteria were developed for both tunnel and surface storage concepts.

The entire United States was screened at two levels of resolution (national and detailed). Favorable areas were identified in 22 states for tunnel facilities covering about 60,000 square miles or 2 percent of the United States. For surface facilities, favorable areas in 36 states covering 650,000 square miles or 20 percent of the United States were identified.

Status of Technology for MRS Concepts

An evaluation of the status of the technology necessary to construct and operate the various MRS concepts was performed. Much of the technology necessary for implementation has been developed, or is being developed and actively tested today for the storage of spent fuel or high-level waste. The review revealed a number of areas where additional research and development would be required before implementation.

A major question remaining concerns the information that would be required to obtain a license for such a facility. Although Title 10, Part 72, of the Code of Federal Regulations has been issued, the U.S. Nuclear Regulatory Commission has not licensed a facility under this regulation. Therefore, any conclusion regarding the need for additional research and development must be tentative.

MRS Demonstration Facilities

Demonstration facilities that could process up to 2000 packages of both spent fuel and high-level waste with the capability to be expanded into a full-scale facility have been described. Two DOE sites were used as the basis for the design of the facilities and three different MRS concepts were considered. For the Hanford Site, the open-field dry wells and tunnel-rack concepts were investigated. At the Nevada Test Site (NTS), the concepts investigated were open-field dry wells and tunnel dry wells. The estimates of capital cost for these facilities at the Hanford Site and the Nevada Test Site are as follows:

Hanford Site
  Open-field dry wells: $245,000,000
  Tunnel rack: $341,000,000

Nevada Test Site
  Open-field dry wells: $144,000,000
  Tunnel dry wells: $352,000,000

The significant differences in cost result from details in the assumptions used in the design studies. For example, at Hanford, provisions were included for receiving and handling material in a water basin with significant space for lag storage. The NTS design study assumes that all handling would be in air and no provisions were allowed for lag storage. For the dry wells, there are different allowances for corrosion that result in different costs for canisters and dry-well liners.

The length of time estimated to complete a demonstration facility on a DOE site is between 9 and 11 years. The schedules developed reflected all procedures that would have to be followed beginning with Congressional authorization and including competitive procurement of the architect-engineer to design the facility, the requirements to fulfill National Environmental Policy Act responsibilities, and the time to obtain a license for the facility. Acceleration of this schedule would likely require clarification of procedural requirements by Congress.

1 Introduction

The Conference Report on H.R. 7590 (House Report No. 96-1366) for the appropriations for Energy and Water Development for fiscal year 1981 directed that the U.S. Department of Energy (DOE) conduct investigations, research, and support studies for monitored retrievable storage (MRS) repositories and prepare a site-specific report for such a repository. A more specific requirement was outlined in S. 2189 (The Nuclear Waste Policy Act--Report Together with Supplemental Views of the Senate Committee on Energy and Natural Resources, Senate Report No. 96-548, January 3, 1980), which was passed by the Senate in July 1980, but was not voted into law. This bill would have required that a study, to be delivered in 1 year, provide both a general description, cost estimates, and construction schedules for a system of MRS repositories and site-specific designs, specifications, and cost estimates for a demonstration facility with adequate detail to enable the solicitation of construction bids.

This report has been prepared in response to the directions in House Report No. 96-1366. The intent of this study was drawn, in part, from the text of S. 2189, although the specific requirement to produce a design with enough detail for the solicitation of construction bids was not possible with the resources available or within the time of 1 year.

The concept of monitored retrievable storage for the long-term management of radioactive waste originated in the 1950s. Initially, the concept was applied to the indefinite storage of high-level liquid waste resulting from reprocessing. The long-term storage of such waste in steel tanks was a basis (S. M. Stoller Associates, 1962) for the license given to the Nuclear Fuel Services Corporation for its reprocessing plant at West Valley, New York. In 1972, the development of a Retrievable Surface Storage Facility (RSSF) was proposed (AEC, 1972; Atlantic Richfield Hanford Company, 1974) as the primary site for the storage of high-level solid waste and transuranic waste resulting from reprocessing; this would allow the development of permanent disposal facilities on a longer term basis. In 1974, the U.S. Atomic Energy Commission (AEC) issued a draft environmental impact statement on the development of the Retrievable Surface Storage Facility for review and comment (AEC, 1974). Negative reactions to this draft statement were received (Lash and Bryson, 1974; Messing, 1974) from a diverse group that viewed the proposed facility as only an interim measure and felt that adequate consideration had not been given to permanent disposal.

The reaction of the U.S. Environmental Protection Agency (EPA) was also negative. The Director for EPA's Office of Federal Activities stated in a letter (Meyers, 1974):

> We believe that questions surrounding the management of high-level and transuranic wastes should be explored in

> the context of an overall waste management program that includes a vigorous effort towards ultimate waste disposal. The draft statement concentrates, to a large degree, on the facet of interim storage--covering topics such as the short-term suitability of technical containment, the Federal responsibilities for custody of radwaste, and the proper treatment of transuranium-contaminated waste. Although these topics are reasonably treated in the draft statement, the question of ultimate disposal is not.
>
> ...In light of this situation, we feel that the AEC's waste-management program, as reflected in this draft statement, has not adequately addressed the high-level waste disposal problem.

After the creation of the U.S. Energy Research and Development Administration (ERDA) in 1974, its Administrator ordered the withdrawal of the draft RSSF environmental impact statement, and stated (ERDA, 1975) that "ERDA, in assuming responsibility for this environmental program, has taken a fresh look at the status of environmental planning and review and we have determined that the objectives of the National Environmental Policy Act would best be served by preparation of an expanded environmental impact statement before ERDA commits itself to the construction of an RSSF." The U.S. Energy Research and Development Administration then embarked on a program dedicated to the development of geologic repositories for the permanent disposal of high-level waste (ERDA, 1976).

Interest in a monitored retrievable system for the long-term storage of either solidified high-level wastes or unreprocessed nuclear reactor fuel has recently been rekindled. Discussion of the concept has occurred in the open literature (Hammond, 1979) and in Congressional committee hearings (Subcommittee on Energy Regulation, 1979a,b). In the conference report for the fiscal year 1981 appropriations for Energy and Water Development, the U.S. Department of Energy was directed to perform studies of the feasibility of a system of MRS repositories for the long-term storage of radioactive wastes.

Such studies have considered the status of the technology required for the concept, probable licensing requirements, the appropriate role of the MRS system in the total waste-management system, and possible sites for the regional placement of MRS facilities. A number of designs for MRS facilities were considered; conceptual designs and preliminary cost estimates have been prepared for three promising concepts that could be sited on two DOE sites.

These feasibility studies focused on answering the following basic questions:

1. What is (are) the preferred role(s) of the MRS facility, what is its impact, and how does it compare with alternatives in the overall waste-management system?
2. Where could MRS facilities be located?
3. What would an MRS system look like and in what way and to what degree does monitored retrievable storage contribute to public health and safety? Is it licensable* under existing regulations?
4. What would an MRS system cost?
5. How long would it take to implement an MRS system?
6. What concept would be selected for demonstration facilities, where could they be built, when could they be licensed and put into operation, and what would they cost to construct and operate?

Contractors that conducted the studies are listed below.

Contractor	Work scope
General Atomic Company	Evaluate total waste-management systems to determine the contribution of an MRS facility
	Develop a generic conceptual design for the storage concept of an MRS system using rack storage in tunnels
	Evaluate the various technical approaches that could be used for an MRS facility
	Evaluate the status of technology for implementing each MRS concept
Woodward-Clyde Consultants	Develop site screening criteria that could be used to site a surface-based or tunnel-based MRS facility

---

*The discussion of licensing of MRS facilities is based on the understanding of the requirements by the DOE staff and contractors. This report has not been reviewed prior to issuance by the NRC.

Contractor	Work scope
Woodward-Clyde Consultants (continued)	Conduct a screening of the United States to determine where MRS facilities might be located Conduct a sensitivity analysis to determine how the screening criteria affected the available land area for siting
Rockwell Hanford Operations/ Kaiser Engineers	Develop a site-specific conceptual design for a demonstration facility at the Hanford Site.
Edison Electric Institute,* Westinghouse Electric Corporation, Bechtel National, Inc., and EG&G	Develop a conceptual design for a spent-fuel storage facility in an arid climate that would serve as a basis for a conceptual design of a demonstration facility at the Nevada Test Site
NUS Corporation	Coordinate and support the performance of the study; review and prepare the summary report

---

*Edison Electric Institute was a co-sponsor of this study.

References for Chapter 1

AEC (U.S. Atomic Energy Commission). 1972. "AEC Announces Plans for Management of High-Level Radioactive Waste." Press Release P-143, Washington, D.C.

AEC (U.S. Atomic Energy Commission). 1974. Management of Commercial High Level and Transuranium-Contaminated Radioactive Waste. Draft environmental statement, WASH-1539, Washington, D.C.

Atlantic Richfield Hanford Company, Kaiser Engineers. 1974. Retrievable Surface Storage Facility Alternative Concepts Engineering Studies. ARH-2888 REV, Richland, Wash.

ERDA (U.S. Energy Research and Development Administration). 1975. "ERDA to Issue Expanded Environmental Impact Statement on Management of Commercial High-Level and Transuranium Contaminated Waste." Press Release 75-71, Washington, D.C.

ERDA (U.S. Energy Research and Development Administration). 1976. "ERDA Studies Geologic Formations Throughout Nation for Data on Potential Sites for Commercial Nuclear Waste Disposal." Press Release 76-355, Washington, D.C.

Hammond, R. P. 1979. "Nuclear Wastes and Public Acceptance." American Scientist, Vol. 67, pp. 146-150.

Lash, T. R., and J. E. Bryson. 1974. NRDC Comments on WASH-1539. Letter (October 24, 1974) to Dr. J. L. Liverman, U.S. Energy Research and Development Administration.

Messing, M. 1974. Environmental Policy Center Comments on WASH-1539. Letter (December 12, 1974) to Dr. J. L. Liverman, U.S. Energy Research and Development Administration.

Meyers, S. 1974. U.S. EPA Comments on WASH-1539. Letter (November 21, 1974) to Dr. J. L. Liverman, U.S. Energy Research and Development Administration.

S. M. Stoller Associates. 1962. The Perpetual Care of High Level Radioactive Liquid Waste in New York State, A Technological and Cost Study. New York, N.Y.

Subcommittee on Energy Regulation. 1979a. Hearings Before the Subcommittee on Energy Regulation, Vol. 19, Publication No. 96-38, Part 1. Government Printing Office, Washington, D.C.

Subcommittee on Energy Regulation. 1979b. Hearings Before the Subcommittee on Energy Regulation, Vol. 19, Publication No. 96-38, Part 2. Government Printing Office, Washington, D.C.

2 Waste-Management Systems Analysis

This chapter examines the radioactive-waste-management system, evaluates the characteristics and benefits of monitored retrievable storage (MRS), and determines the ways in which MRS concepts might contribute to the safe and efficient management of radioactive waste.

2.1 Elements of the waste-management system

The waste-management system consists of facilities and services for receiving, storing, processing, transporting and disposing all radioactive waste generated in the nuclear fuel cycle from mining, milling, conversion, enrichment, fuel fabrication, reactor operation, spent-fuel management, and reprocessing. The intent of this section is to identify the types of waste generated by the major elements of the "back end" of the nuclear fuel cycle, namely reactors, spent-fuel storage facilities, and reprocessing facilities, as well as the requirements for the disposal of the different types of wastes. The discussion of waste-disposal requirements must take into account the fact that spent fuel contains both resources (uranium and plutonium) and wastes (fission products and transuranic contaminants). The storage of spent fuel is considered a waste-management operation until the waste is separated from the spent fuel or the spent fuel is disposed of permanently.

Low-level radioactive waste is not considered in this analysis. A separate system of handling low-level waste from all fuel-cycle facilities is in place and operating under the regulation of the Nuclear Regulatory Commission or Agreement States.

Transuranic waste is that radioactive waste that contains more than 10 nanocuries of transuranic radionuclides per gram of material. Because of contamination of the waste with transuranic elements, radionuclides that are more toxic to humans and animals than fission products, special requirements have been established for its handling and disposal. Such waste, even when only mildly radioactive, cannot be disposed of by shallow land burial.

High-level wastes have been defined by law and regulations as the aqueous stream of the first cycle of solvent extraction in the reprocessing of nuclear fuel. This stream contains the bulk of the fission products from the nuclear fuel. It is these fission products that require the designation of "high level" because of their radioactivity. Strictly speaking, therefore, the fission products themselves can be considered as high-level wastes, even when they are still contained within the ceramic fuel pellets in the reactor fuel.

The waste-management system, as it has been traditionally defined, has five major components. These components are the reactor, interim spent-fuel storage, the reprocessing plant, the repository, and transportation. The function that each component performs in the waste-management system is discussed below.

Waste management at reactor power plants

The reactor is the prime "creator" of radioactive waste, creating two types of waste: (1) low-level waste retained in auxiliary cleanup equipment and (2) high-level waste retained in the spent-fuel elements. Low-level waste is sent to low-level burial grounds. Spent fuel is held at the reactor in water-cooled storage pools or shipped offsite to interim storage facilities pending reprocessing or disposal.

A survey (DOE, 1981) of utilities conducted by the Department of Energy (DOE) in 1980 indicated that the storage capacity for spent fuel at reactors will be inadequate in the near future. Depending on whether or not interfacility spent-fuel transfers are allowed, a projected shortfall of storage space was forecast between 1985 and 1987.

The 70 reactors now in operation discharge spent-fuel assemblies at a rate of approximately 1600 metric tons of heavy metal (MTHM) per year. When the 90 additional reactors now under construction or in the licensing process begin operation, the discharge rate will reach 4200 MTHM/yr.

Short-term interim storage

The short-term interim storage facility has traditionally been a larger version of the storage pools maintained at a reactor. The storage of spent fuel in water pools has been practiced successfully for over 20 years. During storage, the pool water serves as a radiation shield, a heat-transfer medium to dissipate the heat generated in spent fuel, a containment medium to capture radionuclides that leak from the spent fuel, and an environment for which the chemistry can be controlled to prevent excessive degradation of the fuel-rod cladding.

New radionuclides are not generated at a water basin. It is a holding place for the waste in the spent fuel before shipment to a reprocessing plant or a disposal facility. Low-level wastes are generated by the filtration and demineralization system that controls the chemistry of the pool water and removes any radionuclides released from the spent fuel. These wastes are shipped to low-level burial grounds. As indicated above, the at-reactor pool storage capacity will be inadequate and additional spent-fuel storage capacity will be required in the 1985 to 1992 time frame. Since it can be expected that Federal repositories will not be available until the late 1990s (DOE, 1980a), or, if reinstituted, reprocessing will not be available until the early 1990s, some form of interim storage will be required.

Interim storage facilities must now be licensed under Title 10, Part 72, of the Code of Federal Regulations with the license limited to 20 years. This limit has been set for administrative purposes and does not represent a technical limitation on such facilities. No facility has yet been licensed under the new regulations.

Reprocessing

The purpose of reprocessing spent fuel is to recover unused fissile material for reuse in reactors. During reprocessing, several types of waste are generated, including high-level liquid waste that must subsequently be solidified; transuranic-contaminated waste that includes cladding hulls, failed equipment, compactible and combustible waste, and wet particulate waste; condensed radioactive gases; and low-level waste. It has been estimated that the volume of transuranic waste from reprocessing will be greater than the volume of solidified high-level waste by a factor of 8 to 10.

High-level liquid waste must be solidified within 5 years of reprocessing; the solidified high-level waste can be stored at the reprocessing plant for an additional 5 years. At the end of that time it must be turned over to the Federal Government. High-level waste is to be disposed of in a geologic repository. Transuranic-contaminated waste is also scheduled to be sent to a repository. Low-level waste is sent to low-level burial grounds.

Reprocessing is not an operating part of the fuel cycle at this time. For the purpose of this study, it was assumed the first reprocessing facility would begin operation in 1990 with a capacity of 1500 MTHM/yr. The second and third reprocessing plants of the same capacity would begin operation in the years 2000 and 2010, respectively.

Geologic repositories

The geologic repository is the final step in the waste-management system for solidified high-level waste and transuranic-contaminated waste. This facility will provide passive disposal of the waste that, once filled and sealed, should require no additional care from man.

The first repository is currently forecast to be in operation between 1997 and 2006.

Transportation

Transportation is a service in the waste-management system required to move material from one place to another. In the process of loading waste for shipment, the containers in which it is shipped often become contaminated. Periodic decontamination of shipping containers generates a small volume of low-level radioactive waste.

2.2 Characteristics of monitored retrievable storage

The concept (Hammond, 1979) of monitored retrievable storage for commercial spent-fuel elements and high-level waste is based on using a high-integrity hermetically sealed canister for the containment of the radionuclides and a structure of some type to protect the canister from natural or man-caused events. Cooling is generally provided by a passive method (e.g., natural convection to the air) in order to eliminate the need for continuous operation of such machinery as water pumps or cooling fans and continuous maintenance.

Various concepts for long-term storage using passive cooling are described in greater detail in Chapter 4. In general, the concepts considered involve the following:

1. Storage in holes drilled into the ground, referred to as "dry wells"
2. Storage in concrete structures or casks
3. Storage in tunnels designed to provide cooling by natural draft

During the time that radioactive materials are stored, continuous monitoring (visual and with scientific instruments) would be conducted to prevent and minimize the release of radionuclides to the environment. The facility would provide for the retrieval of the canister of waste at any time during storage and at the end of the facility's useful life. The period of operation of a facility could extend to 300 years. In this study, interim storage periods of 100 years were assumed.

Any monitored retrievable storage would have to be integrated into the waste-management system. In examining this integration, the following assumptions were made:

1. MRS facilities would not be co-located with geologic repositories.
2. MRS facilities would be licensed under Title 10, Part 72, of the Code of Federal Regulations (NRC, 1980a.).
3. Existing technology would be the basis for such a facility.
4. A system of facilities would be designed to accommodate the total existing and projected quantity of spent fuel and high-level waste from all domestic commercial nuclear power plants currently licensed or in any stage of the Federal licensing process as of January 1981. (This requires provision of storage space for approximately 145,000 MTHM in spent-fuel elements--the output from 150-gigawatts electric-generating capacity operating for 35 years.)

5. The impact on the waste-management system of any further use of nuclear power beyond the output of 150 gigawatts electric was not considered.

6. Three MRS facilities would be used to accommodate either spent fuel or processed high-level waste.

7. Material would be delivered by truck and train.

2.3 Potential roles for monitored retrievable storage

A review of the description of the waste-management system and the characteristics of the MRS concept indicates that the role of monitored retrievable storage should be limited to the storage of either spent fuel or high-level waste. There are currently three potential ways that monitored retrievable storage could be used. They are the following:

1. Interim storage of spent fuel before reprocessing

2. Storage of spent fuel or high-level waste before disposal in a geologic repository

3. Indefinite storage (or disposal) of spent fuel or high-level waste

The first approach would use monitored retrievable storage to provide dry away-from-reactor (AFR) storage of spent fuel. This option was investigated in a study funded jointly by the Edison Electric Institute and the Department of Energy as a potential method for interim storage of spent fuel until reprocessing is available (Westinghouse, 1981). The study evaluated the requirements of facilities to handle the storage of spent fuel that cannot be stored at reactors.

A storage capacity of 30,000 MTHM of spent fuel was established as the additional storage requirement on the basis of projections of shortfall (DOE, 1981) through the year 2010.

It was assumed that three facilities, each with a spent-fuel capacity of 10,000 MTHM, would be built as a private venture. It was estimated that a period of 6 years would be required to design, license, and build the first facility after the selection of a site. The analysis assumed that the site selection would occur in 1982; therefore, the facility would be operational in 1988. By contrast, the schedule (Figure 6-11) in Chapter 6 indicates that a demonstration facility built by the Government could require approximately 9 to 11 years to complete because of lead time for Congressional authorization, preparation and public review of the environmental impact statement, procurement of an architect-engineer firm for design, and more conservative estimates of the time for licensing review and approval.

The ability to provide such a facility by the projected date of 1988 depends on two major factors. The first is that some consortium, partnership, or other venture must be organized to manage such a project. The second is the span of time that might be required to obtain a license for such a facility. The referenced study assumed that a construction permit could be obtained in 1.5 years. Because no license has ever been issued under Title 10, Part 72, of the Code of Federal Regulations, no experience is available against which to judge this estimate.

Two concepts of interim storage were evaluated: dry wells in tunnels and dry wells in an open field. These concepts are described in Chapter 4. The capital cost estimate for a 10,000-MTHM capacity tunnel dry-well facility was $992 million and for the open-field dry well, $340 million. Based on an assumed storage period that ranged from 20 to 60 years, and varying assumptions regarding the long-term financing of the facility, the estimated storage fee a utility would be charged on delivery of the spent fuel ranged from $100 to $170 per kilogram of heavy metal (kgHM) for the open field. The estimated fee based on the set of assumptions that were considered most likely to be accepted was $160/kgHM for open-field dry well and $340/kgHM for tunnel dry wells.

The second approach would use monitored retrievable storage for long-term storage of spent fuel or high-level waste for a period up to 100 years to allow the thermal power output to decrease before emplacement in a geologic repository. Allowing the waste to cool before disposal in a geologic repository would affect the characteristics of a repository.

The thermal power output of spent fuel is approximately 1.2 kilowatts per MTHM (kW/MTHM) at 10 years out of the reactor and 0.3 kW/MTHM at 100 years. Similarly, high-level waste from a light-water reactor uranium-plutonium recycle has a power level of 2.3 kW/MTHM at 10 years and 0.2 kW/MTHM at 100 years. Of the total thermal energy released by a spent-fuel element between 10 years and 1000 years out of the reactor, 30 percent is released during the period of 10 to 100 years. For solidified high-level waste from a uranium-plutonium recycle, the amount that is released between 10 and 100 years is 50 percent.

Repository construction and operation costs would be reduced by delaying repository development by 100 years. These reductions would be achieved by (1) placing more waste in each waste package; (2) placing the waste packages closer together, thereby reducing mining costs, and (3) using less and inexpensive material in the fabrication of the waste package. The first two methods are interdependent, both being a function of the thermal power output of the waste and the total amount of energy released into the formation.

The amount of high-level waste in a package can be changed by increasing the proportion of radionuclides in the glass or the degree of disassembly of the spent-fuel elements, or by increasing the size of the waste package.

For solidified high-level waste in a salt repository, it is estimated (Rickertsen, 1980) that 81 MTHM/acre could be disposed of at 10 years out of the reactor, 100 MTHM/acre at 50 years, and 120 MTHM/acre at 100 years. If the repository were in granite or basalt, it could accommodate 103 MTHM/acre at 10 years, 223 MTHM/acre at 50 years, and 370 MTHM/acre at 100 years. These improvements in disposal space efficiency could result in about a 40 percent reduction in the cost of repositories. However, because of additional cost of interim storage facilities and research and development the total cost of a 100-year delay would be approximately 20 percent greater than the current program. This figure presents a lower limit of the total cost increase because it has no provision for the cost of long-term interim storage of transuranic-contaminated waste produced during reprocessing.

The above discussion illustrates the basis for possible cost savings that a repository could achieve from 100 years of cooling. Alternatively, greater conservatism in the technical design of a repository could be achieved. If the initial layout of the repository were maintained and waste emplaced had one-tenth the thermal power, the temperature increase the repository would experience would be about one-tenth that experienced if the waste were emplaced immediately. However, it is not possible at this time to quantify the improvement that this would have on the safety of the repository.

The third approach would use the MRS facility as the permanent method for disposal. This approach would replace a totally passive disposal method of the geologic repository with one that assumes an active management role by man to maintain and replace these facilities in perpetuity. An advantage of this approach might be that the integrity of the containment would always be known. Disadvantages would be the commitment that must be made to maintain the disposal operation, the uncertainty in the level of institutional control that would be provided in distant future years, and the unknown long-term safety of the method in the context of natural and man-caused events since the waste is still within the sphere of man's environment.

In order to evaluate the waste-management system and monitored retrievable storage, eight different cases based on four scenarios were developed. The following four scenarios were considered:

1. Spent-fuel disposal using reactor facilities and repositories
2. Spent-fuel disposal using MRS facilities
3. Fuel reprocessing with high-level-waste disposal directly in repositories
4. Fuel reprocessing with high-level-waste storage or disposal in MRS facilities

Eight cases under the 4 scenarios were then developed as follows:

1A--Spent-fuel disposal in a repository starting in the year 2000 with interim storage at expanded reactor pools

1B--Spent-fuel disposal in a repository starting in the year 2000 with interim storage at away-from-reactor facilities

2A--Spent-fuel disposal in a repository starting in the year 2000 with interim storage at the MRS facility

2B--Spent-fuel disposal in a repository with interim storage at the MRS facility, 100-year-old fuel

2C--Spent-fuel disposal in the MRS

3--High-level-waste disposal with interim storage at a reprocessing facility

4B--High-level-waste disposal with interim storage at the MRS facility, 100-year-old waste

4C--High-level-waste disposal at the MRS facility

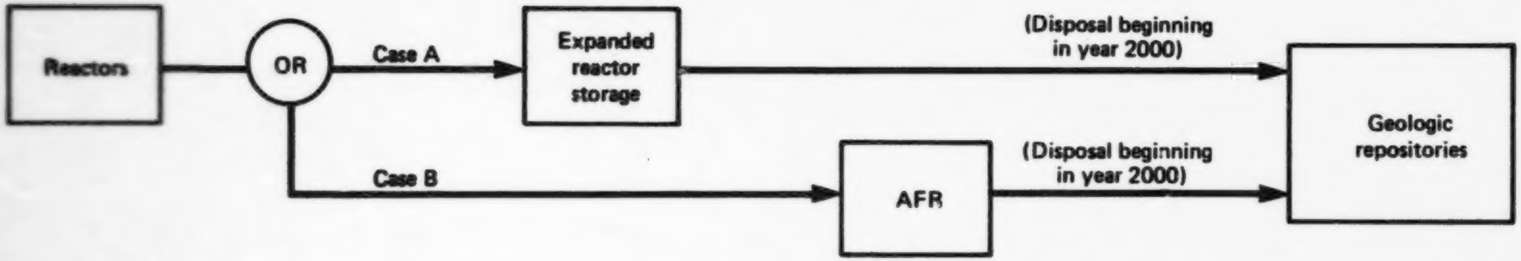
A flow diagram for each of the scenarios defined above is provided in Figures 2-1 and 2-2. A description of each scenario is provided below.

Scenario 1 - Case A

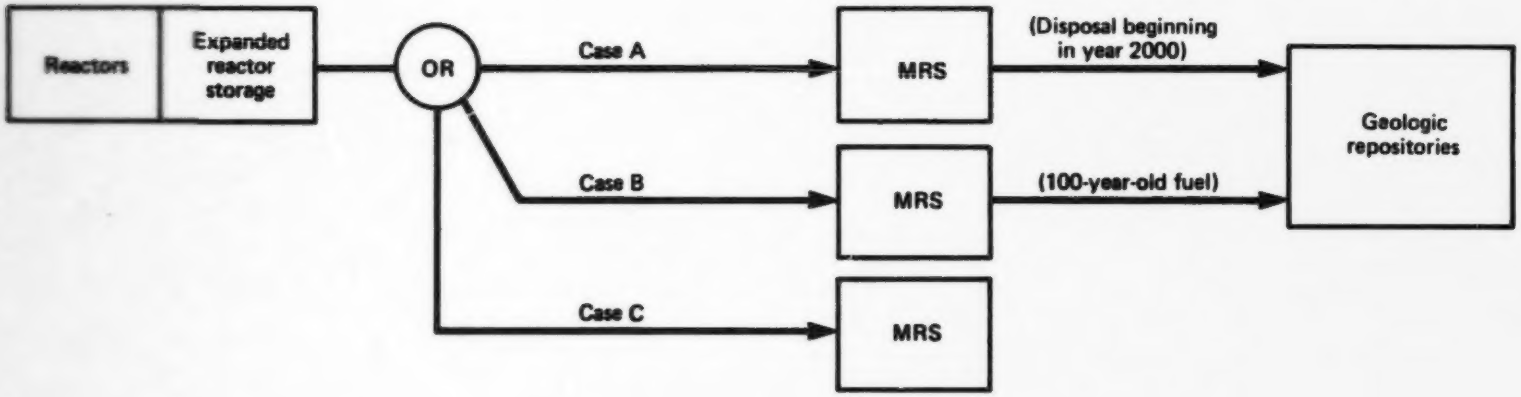
Spent fuel is stored at the reactor sites until geologic repositories are available in the year 2000. Each reactor is assumed to maintain full-core discharge capability and no interfacility transfers are considered. These assumptions would require the addition of new spent-fuel storage facilities at reactor stations. Sufficient capacities could be provided through a variety of approaches available to the utility companies. For the purpose of this analysis, it was assumed that new spent-fuel storage pools would be constructed with capacities ranging from 400 to 1600 MTHM, as necessary at each reactor site, with a total capacity of 37,400 MTHM. Three repositories, to begin operation in the years 2000, 2003, and 2006, would receive spent fuel at 1800 MTHM/yr each for the first 5 years followed by 6000 MTHM/yr each for subsequent years.

Scenario 1 - Case B

This scenario assumes that five regionally located pool facilities would be used with each one becoming operational as required. Shipments to each facility would be as required by each reactor plant to maintain full-core reserve. The first two pool facilities are assumed to be the existing General Electric Reprocessing Plant at Morris, Illinois, and the Allied-General Reprocessing

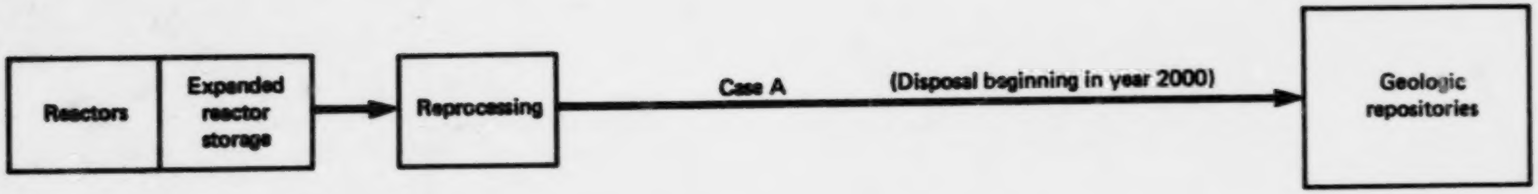

Reactors
OR
Case A
Expanded reactor storage
(Disposal beginning in year 2000)
Geologic repositories
Case B
AFR
(Disposal beginning in year 2000)

Scenario 1—Spent-fuel disposal

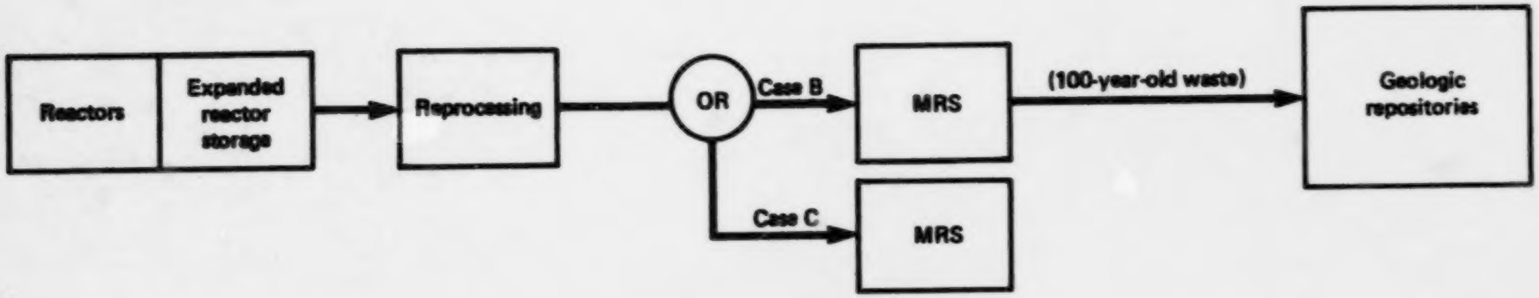

Reactors
Expanded reactor storage
OR
Case A
MRS
(Disposal beginning in year 2000)
Geologic repositories
Case B
MRS
(100-year-old fuel)
Case C
MRS

Scenario 2—Spent-fuel disposal using MRS

Figure 2-1. Once-through fuel-cycle scenarios.


Reactors
Expanded reactor storage
Reprocessing
Case A
(Disposal beginning in year 2000)
Geologic repositories

Scenario 3—HLW disposal


Reactors
Expanded reactor storage
Reprocessing
OR
Case B
MRS
(100-year-old waste)
Geologic repositories
Case C
MRS

Scenario 4—HLW disposal using MRS

Figure 2-2. Reprocessing fuel-cycle scenarios.

Plant at Barnwell, South Carolina. The other three facilities would be new. The total capacity at each is as follows:

	Total Storage Capacity (MTHM)	Annual Shipping and Receiving Capacity (MTHM/yr)
Morris	1,100	200
Barnwell	1,750	500
AFR-1	5,000	1000
AFR-2	10,000	2000
AFR-3	10,000	2000
Total	27,850	

Fuel would be shipped to the pool facilities until 2002. Starting in the year 2000, some spent fuel would be shipped directly to the repositories from reactor plants, and in the year 2003 all spent fuel from these plants would go directly to the repository. From 2003 through 2009 spent fuel would be shipped from the Government pools to the repositories at rates equal to their design shipping rates.

Scenario 2 - Case A

Spent fuel is stored at reactor sites until the first MRS installation is available in 1990. This would require limited expanded at-reactor storage for those plants that lose full-core discharge capability before 1990. Three MRS installations, to begin operation in 1990, 1993, and 1996, would receive 5-year-old spent fuel at 900 MTHM/yr each until the year 2002. In the year 2000, direct shipments from reactor plants to repositories would begin and by 2003 this procedure would apply for all spent fuel shipped from reactor plants. In addition, beginning in the year 2004, spent fuel would be shipped from the MRS facilities to the repositories at 900 MTHM/yr until all spent fuel has been removed from the MRS facilities in the year 2014. Under this scenario, a total of approximately 23,500 MTHM of spent fuel will have been stored in three MRS installations.

Scenario 2 - Case B

This scenario assumes a requirement that spent fuel be cooled for 100 years before final deposition in a geologic repository. The initial flow of spent fuel into three MRS installations is identical to that in Scenario 2A. However, the shipment of 5-year-old fuel from reactor plants to MRS facilities continues beyond the year 2002 at 900 MTHM/yr to each of the installations until the year 2050. Spent fuel remains in the MRS facilities until the 100-year cooling requirement is reached. Then, in the year 2076, shipments of 100-year-old spent fuel from the MRS facilities to the repository begin at a rate of 900 MTHM/yr/installation. This retrieval from monitored retrievable storage continues until 2132 when all three installations are empty. Under this scenario, a total of approximately 145,000 MTHM of spent fuel will have been stored in three MRS installations.

In order to account for the potential benefit of cooling wastes for 100 years before placing them in a repository, the following cost savings were assumed for the repository:

1. A 20 percent reduction in capital cost
2. A 50 percent reduction in variable operating cost
3. A 20 percent reduction in fixed operating cost

It was further assumed that research and development expenditures for repositories would fall from roughly $200 million in 1982 to $50 million per year beginning in 1985. This level was maintained constant and assumed to be sufficient to keep investigations for suitable permanent repositories under way until the decision is made regarding permanent disposal. Roughly 12 years before the first repository opens, funding increases to permit necessary remaining research and development.

Scenario 2 - Case C

This scenario assumes cooling of spent fuel in MRS installations for an indefinite length of time. The flow of spent fuel into and out of three MRS installations is identical to that in Scenario 2B. However, after 100 years of cooling, the spent fuel is transferred into three new MRS installations instead of geologic repositories. This type of transfer would be repeated approximately every 100 years indefinitely.

Research and development was handled in the same way as in Scenario 2B, except that it was terminated when construction of the first replacement MRS facility begins in 2067.

Scenario 3

Spent fuel is stored at the reactor sites as described in Scenario 1A until it can be shipped to one of three reprocessing plants, the first to become operational in 1990. A total of 6700 MTHM of additional storage capacity is required at reactors. Storage will continue until the year 2023 when further capacity is no longer required. The high-level waste generated is stored at the reprocessing plant for as long as 10 years (up to 5 years in liquid form and 5 years in solid form) until it may be shipped directly to a repository beginning in the year 2000. The storage of additional waste at the reprocessing plant is required only until the waste has cooled to a heat output acceptable for repository deposition.

Scenario 4 - Case A

This case, which would use MRS facilities to store high-level waste, was not analyzed because all such waste generated from reprocessing could be stored at reprocessing plants, obviating the need for an MRS facility.

Scenario 4 - Case B

Spent fuel is stored at the reactor sites until it can be shipped to one of three reprocessing plants, the first to become operational in 1990. The high-level waste generated is stored at the reprocessing plant until it reaches a heat output of 3 kilowatts per high-level waste canister (projected heat output of 10-year-old solidified waste) when it may be shipped to MRS installations. These shipments begin in the year 2000 at 1500 MTHM (equivalent) per year per installation. This rate is increased to 3000 MTHM (equivalent) per year in the year 2010 and to 4500 MTHM (equivalent) in the year 2020. The MRS installations continue to receive high-level waste at this rate until 2044. High-level waste remains in monitored retrievable storage until the 100-year equivalent cooling requirement from time of reactor discharge is reached. Then, in 2076, shipments of high-level waste from monitored retrievable storage to repositories begin at a rate of 1500 MTHM/yr/installation. This retrieval from monitored retrievable storage continues until all three installations are empty in 2127.

The treatment given repository costs and research and development funding in Scenario 2B is also applied to this case. However, the base repository costs were different, reflecting different costs for a repository handling high-level waste instead of spent fuel.

Scenario 4 - Case C

This scenario assumes cooling of high-level waste in MRS facilities for an indefinite length of time. The flow of spent fuel and high-level waste is identical to that in Scenario 4B. However, after 100 equivalent years of cooling, the high-level waste is transferred into three new MRS installations instead of geologic repositories. This type of transfer would be repeated approximately every 100 years indefinitely.

The treatment given research and development funding in Scenario 2C is also applied to this case.

2.4 MRS impact on the waste-management system

Health and safety, system cost, and public acceptance are considered to be three major areas affected by monitored retrievable storage. Each of these three subject areas is discussed below.

2.4.1 Health and safety

Based on a review (General Atomic, 1981) of the available design information for various MRS concepts, no technical reason has been identified that would prevent an MRS concept from being licensed under current regulatory practices, (NRC, 1980a) although the question of a 100-year license will need to be addressed. Therefore, it appears that monitored retrievable storage could provide a long-term storage capability at a level of safety comparable to that now judged acceptable for the nuclear waste-management system.

The above conclusion is drawn from a qualitative comparison of the technologies and design approaches used in the MRS concepts compared to those now in use, or proposed for use, in spent-fuel storage in water basins. The Advisory Committee on Reactor Safeguards, in addressing itself to the issue of the safe storage of spent fuel, has stated (Plesset, 1980) that

> In our review of whether waste in the form of spent fuel can be safely stored pending its safe disposal, we assume initially a required storage duration of about 30 additional years, that is, until about the year 2010. This is consistent with the date of 1997-2006 when DOE has stated that it will have disposal facilities in operation. As discussed below, we believe that safe interim storage well beyond 30 years can be provided should it be required.
>
> The safety and practicality of interim storage of spent fuel has already been demonstrated for periods of 15-20 years. We believe there is no reasonable doubt that, with continued maintenance and surveillance, safe storage could be continued very much longer barring the occurrence of an unanticipated catastrophic external event. The reason for this confidence is not only the demonstrated performance cited above but the compelling logic that fuel and cladding materials which maintain their integrity under the severe environments of operating reactors will be essentially inert in the relatively benign environment of a storage water basin where the governing corrosion and diffusion rates are at least a few orders of magnitude less. Additionally, a spent fuel storage basin, unlike an operating reactor, has so little latent energy that it is much less subject than an operating reactor to sudden and possibly damaging effects by accident or malfunction. If, in spite of all expectations, an accident should occur, there should be time to deal with it and prevent any serious consequence.
>
> An alternate method of storage, dry storage, has been extensively studied in the U.S., Canada, Europe, and elsewhere with satisfactory results. Although this method lacks the extent of demonstrated use compared to the water basin storage, we believe it warrants serious consideration because with longer aged spent fuel a simpler and more passive design is possible. Therefore, dry storage is even less susceptible to malfunctions.

It should be noted that spent fuel, because of its decay heat, must be stored in water basins for the first few years after reactor discharge. Only after about 5 years of cooling in water can spent fuel be considered for passive dry storage. Dry storage of a variety of types of spent fuels has been tested and demonstrated in casks, vaults, and dry wells for periods of up to 15 years without incident (NRC, 1980b). The extrapolation of this experience, of other dry storage experience, or of water-basin storage to monitored retrievable storage must include recognition of the different time frame envisioned for monitored retrievable storage, 100 years or more.

A quantitive assessment of risk to the public health and safety (including occupational risk) requires an analysis of detailed designs under assumed normal and off-normal situations. Such an analysis was not performed during the course of this study but should be provided as an important item of information before a final decision could be made to proceed with this concept as an integral part of the waste-management system.

2.4.2 System costs

The cost of monitored retrievable storage facilities and their impact on costs in the balance of the waste-management system, including demands on Government funding, have been evaluated. The results of this evaluation are presented in the following five parts:

1. Economic ground rules and methodology
2. Costs of selected MRS designs
3. Costs of selected waste-management scenarios, with and without MRS
4. Cost sensitivities to key financial and operational assumptions
5. Government funding profiles for selected waste-management scenarios

2.4.2.1 General economic base

For each of the cases presented in Figures 2-1 and 2-2, the time-dependent capital, operating and maintenance, and decommissioning costs for each component in the waste-management system were estimated in 1981 dollars. The analysis presented here is based on a "constant dollar" approach in which the effects of inflation are eliminated from both the discount rate and the time-dependent requirements for funds. Comparisons were developed in terms of both total undiscounted costs in dollars and the discounted unit costs in dollars per kgHM.

The undiscounted costs are the arithmetic sum of all monies spent without regard to when they are spent. These costs may be thought of as a present day best estimate of what the system will cost, exclusive of future inflation.

On the other hand, the estimate of the discounted unit cost will depend on both when monies are spent and when revenues will be collected to pay for storage and disposal. To establish a reference for the cost analysis with regard to the collection of revenue, the time when the spent fuel will be discharged from the reactor was arbitrarily chosen as the point when money would be set aside for its storage and disposal. Revenue for spent fuel currently being stored in reactor storage pools was assumed to be collected in 1981. Costs were estimated for each year of development, construction, and operation.

The revenues from spent-fuel storage referenced against the date of discharge and the estimated costs were discounted to a present value in 1981 using a 3 percent discount rate. The unit cost was then established so that the present value of the revenues equaled the sum of the present value of all costs being considered. The methodology used in the analysis is similar to that specified by the Department of Energy for the evaluation of the cost and associated fee for spent-fuel storage (DOE, 1980b).

The discounted unit cost calculated in this analysis is not a fee to be collected by the Government, but a representative estimate of costs for purposes of comparison. This unit comparison cost can be considered the amount that would have to be set aside at the time a kilogram of spent fuel is discharged from a reactor to cover the subsequent waste-management costs associated with that kilogram in the future, assuming the real cost of funds in the economy is 3 percent per year (exclusive of inflation). The actual amount that a utility would be required to set aside to cover these costs would depend on the payment schedule established by the Government, the actual weighted cost of capital to the utility, and the ownership assumptions for the individual components of the waste-management system.

2.4.2.2 MRS costs

Cost estimates were prepared for the following three types of MRS facilities based on conceptual designs:

1. Open-field dry well
2. Tunnel rack
3. Tunnel dry well

The estimates were derived from the cost estimates presented in Chapter 6 of this report. That material provides cost estimates for four demonstration facilities--two open-field dry-well designs, one tunnel-rack design and one tunnel dry-well design--that have been adjusted to estimate the costs of full-scale facilities. Two open-field dry-well designs (Alternatives A and B) were carried through the initial cost comparison because they each represent different design philosophies resulting in different estimated costs. Alternative A costs were derived from designs prepared using the Nevada Test Site as a reference location. Alternative B costs came from designs developed using the Hanford Site as a reference location.

Tables 2-1 and 2-2 provide a summary comparison for capital and operating costs. All costs represent the requirements for a single installation with a total filled capacity of approximately 48,000 MTHM of spent fuel or equivalent amounts of high-level waste and a receiving rate of 900 MTHM of spent fuel or about 1800 canisters of spent fuel or high-level waste per year. Three such facilities would be required to handle the total discharge from 150-gigawatts electric-generating capacity.

Annual operating costs are classified according to the following three distinct periods of operation:

1. Fill operations - spent fuel or high-level waste is emplaced

2. Caretaker operations - dormant storage period with no emplacement or removal

3. Retrieval operations - spent fuel or high-level waste is removed

These tables indicate that the cost components vary widely among designs. Because of the markedly different capital costs and corresponding operating costs, the costs of the designs are most appropriately compared using life-cycle costs. Table 2-3 provides a cost comparison of the MRS facilities over the full installation life based on Scenario 2B (100-year-old spent-fuel disposal) described in Section 2.3. Total undiscounted cost represents the sum of capital, operating, and decommissioning costs over the entire project life. At this level, the costs for the first three concepts compare closely. However, the total discounted costs are different because of the variation in the timing of the outlays.

2.4.2.3 Total waste-management-system costs

The cost impact of adding an MRS element to the waste-management system has been evaluated for a once-through fuel cycle and reprocessing fuel cycle. The scenarios described in Section 2.3 were used as bases for economic models, the methodology for which was presented in Section 2.4.2.1.

The analyses consider each element of the waste-management system as a separate cost center. Cost centers are included for storage, transportation, repository disposal, research and development, and Government overhead where applicable in a given scenario. The cost basis for each element of the waste-management system was from established figures presented in Table 2-4. These costs have been developed from published sources referenced in the table.

Tables 2-5 and 2-6 show total undiscounted costs for each element of each scenario in 1981 dollars. Total life-cycle costs estimated

Table 2-1. Cost comparison of alternative MRS concepts[a]

MRS concept	Capital to start of operation[b]	Remaining capital	Decommissioning	Annual fill operations[c]	Annual caretaker operations	Annual retrieval operations
Field dry well[d]						
Alternative A	181	0	50	29.3	2.1	9.1
Alternative B	290	0	50	28.5	1.6	9.1
Tunnel rack	496	253	60	23.3	1.7	4.1
Tunnel dry well	507	0	60	73.0	2.7	10.7

Source: MRS Cost Comparison Working Group, 1981.

[a] Values are in millions of mid-1981 dollars.
[b] Based on Scenario 2B.
[c] Based on 900-MTHM per year filling rate.
[d] Differences between the two field dry-well concepts are discussed in Chapter 6.

Table 2-2. Cost breakdown of alternative MRS concepts[a]

Item	Field dry well		Tunnel rack	Tunnel dry well
	Alternative A	Alternative B		
Capital to start of operation				
Receiving and packaging facility	107.1	194.6	273.4	107.4
Transporter system	3.3	1.5	NA[b]	4.4
Surface storage facilities	17.4	24.6	NA	NA
Underground storage structures	NA	NA	126.9	320.2
Offsite facilities	15.0	15.0	15.0	15.0
Architect-engineering services	38.6	53.8	81.0	60.1
Total	181.4	289.5	496.3	507.1
Remaining capital				
Underground storage structures	NA	NA	253.0	NA
Annual emplacement operations				
Canisters	5.0	9.1	9.9	5.0
Dry wells	6.6	10.4	NA	10.5
Racks	NA	NA	0.8	NA
Operation and maintenance	17.3	9.0	12.6	19.4
Surface storage facilities	0.4	NA	NA	NA
Underground storage structures	NA	NA	NA	38.1
Total	29.3	28.5	23.3	73.0

Source: MRS Cost Comparison Working Group, 1981.

[a] Values are in millions of mid-1981 dollars.
[b] NA = Not applicable.

Table 2-3. Economic evaluation comparison of MRS alternative concepts[a]

MRS concept	Total undiscounted cost[b]	Total discounted cost[b]	Discounted unit comparison referenced to reactor discharge cost ($/kg)
Field dry well			
Alternative A	2400	700	25
Alternative B	2400	800	27
Tunnel rack	2400	900	32
Tunnel dry well	5300	1800	62

[a] Based on Scenario 2B.

[b] Values are in millions of 1981 dollars.

Table 2-4. Summary of cost estimates[a]

Cost center	Description	References	Capital costs	Annual operating costs	Other costs
1. Storage					
A. AFR					
Morris	750 MTHM additional capacity at 200 MTHM/yr handling rate	DOE, 1980a,c; IAEA, 1981	\$55.0[b]	\$4.2[d] receiving/shipping \$2.9[d] storage only	\$5.5[e] for decommissioning spread over 2 yr
Barnwell	1750 MTHM capacity at 500 MTHM/yr handling rate	DOE, 1980a,c; IAEA, 1981	\$165.0[c]	\$7.3[d] receiving/shipping \$5.1[d] storage only	\$16.5[e] for decommissioning spread over 2 yr
AFR-1	5000 MTHM capacity at 1000 MTHM/yr handling rate	DOE, 1980a,b; Dupont, 1978; IAEA, 1981	\$293.2	\$11.0 receiving/shipping \$7.7 storage only	\$29.6[e] for decommissioning spread over 2 yr
AFR-2 and all additional units	10,000 MTHM capacity at 2000 MTHM/yr handling rate	DOE, 1980a,b; Dupont, 1978; IAEA, 1981	\$549.0	\$13.2 receiving/shipping \$7.7 storage only	\$55.0[e] for decommissioning spread over 2 yr
B. At reactor		DOE, 1980d; IAEA, 1978; Fishback, 1981; TVA, 1979			
Small pools	400 MTHM capacity		\$44.9	\$2.3 receiving/shipping	\$4.5[e] for decommissioning spread over 2 yr
	700 MTHM capacity		\$52.8	\$2.6 receiving/shipping	\$5.3[e] for decommissioning spread over 2 yr

Table 2-4. Summary of cost estimates[a] (Continued)

Cost center	Description	References	Capital costs	Annual operating costs	Other costs
1. Storage (cont'd)					
Large pools	1000 MTHM capacity		$59.8	$3.0 receiving/ shipping	$6.0[e] for decommissioning spread over 2 yr
	1600 MTHM capacity		$72.4	$3.6 receiving/ shipping	$7.2[e] for decommissioning spread over 2 yr
C. MRS (spent fuel)	48,000 MTHM capacity at 900 MTHM/yr handling rate	MRS Cost Comparison Working Group, 1981	(f)	(f)	(f)
D. MRS (HLW)	48,000 MTHM equivalent capacity for HLW at 1500 canister/yr handling rate	MRS Cost Comparison Working Group, 1981	(f)	(f)	(f)
2. Transportation	Spent Fuel				
	AFR/MRS to repository	IAEA, 1981;			$0.023868/MTHM[g]
	Reactor to AFR/MRS	ONWI, 1979;			$0.015500/MTHM[h]
	Reactor to repository	DOE, 1979			$0.026200/MTHM[i]
	HLW				
	Repro plant to MRS	IAEA, 1981;			$0.003200/MTHM[j]
	Repro plant to repository	ONWI, 1979;			$0.004700/MTHM[g]
	MRS to repository	DOE, 1979			$0.004700/MTHM[g]

Table 2-4. Summary of cost estimates[a] (Continued)

Cost center	Description	References	Capital costs	Annual operating costs	Other costs
3. Repository and encapsulation					
A. Spent fuel	68,000 MT capacity at 1800 MT/yr handling rate first 5 yr; 6000 MT/yr after 5 yr	ONWI, 1980	$1577.3 plus $23.5 replacement capital after 90,000 canisters	$51.8 fixed plus $0.0168/canister	$216.8 for decommissioning spread over 5 yr
B. HLW	68,000 MT equivalent capacity at 1800 MT/yr handling rate first 5 yr; 6000 MT/yr after 5 yr	ONWI, 1979, 1980	$1414.1	$17.1 fixed plus $0.030/MT HLW	$170.5 for decommissioning spread over 5 yrs
4. Research & development	AFR	DOE, 1980b			$96.7 over 1981-1983 time frame
	MRS	DOE, 1980b			$96.8 over 1982-1985 time frame
	Disposal	ONWI, 1980			$3825 over 1981-2006 time frame for repository open in 2000; $50/yr additional for schedule stretch
5. Government overhead	Storage (MRS/AFR)	DOE, 1980b		$4.4	
	Disposal	DOE, 1980b		$15.4	

Table 2-4. Summary of cost estimates[a] (Continued)

Cost center	Description	References	Capital costs	Annual operating costs	Other costs
6. Repository cooldown benefits[l]	50-yr cooldown	Waddell, 1981b			
	Spent fuel		93% of 3A	85% of 3A	Same as 3A
	HLW		90% of 3B	80% of 3B	Same as 3B
	100-yr cooldown	Waddell, 1981b			
	Spent fuel		86% of 3A	70% of 3A	Same as 3A
	HLW		80% of 3B	60% of 3B	Same as 3B

[a] Values are in millions of 1981 dollars.
[b] Estimates of purchase price for existing facility.
[c] Estimated cost of new AFR with 1750-MT storage capacity.
[d] Derived from corresponding figures for AFR-1 using a scaling factor of 0.6.
[e] Estimated based on 10 percent of capital cost.
[f] See Tables 2-1 and 2-2.
[g] Based on a 1100-mile (1 way) trip, 90/10 rail/truck split.
[h] Based on a 400-mile (1 way) trip, 80/20 rail/truck split.
[i] Based on a 1100-mile (1 way) trip, 80/20 rail/truck split.
[j] Based on a 400-mile (1 way) trip, 90/10 rail/truck split.
[k] Based on 5 percent of capital cost.
[l] No benefit was taken for encapsulation facility.

BEST DOCUMENT AVAILABLE

BEST DOCUMENT AVAILABLE

Table 2-5. Comparative cost evaluation of the waste-management system--spent-fuel disposal

	Total undiscounted cost[a,b]						
Scenario	At-reactor expansion	Away-from-reactors	MRS	Trans-portation	Repository R&D and overhead	Repository	Total
1A--Disposal with storage at reactor expanded pools	7.6	--	--	1.6	3.9	11.4	24.5
1B--Disposal with storage at away-from-reactors	--	2.7	--	3.6	4.0	12.0	22.3
2A--Storage at tunnel-rack MRS facility in the year 2000	1.5	--	2.4	4.2	4.1	11.6	23.8
2A--Storage at open-field dry-well MRS facility in the year 2000	1.5	--	2.1	4.2	4.1	11.6	23.5
2B--Storage at tunnel-rack MRS facility, 100-year-old fuel	1.5	--	7.1	5.8	8.6	10.6	33.6
2B--Storage at open-field dry-well MRS facility, 100-year-old fuel	1.5	--	7.3	5.8	8.6	10.6	33.8
2C--Disposal with tunnel-rack MRS only	1.5	--	(c)	(c)	5.4	0	(c)
2C--Disposal with open-field dry-well MRS only	1.5	--	(c)	(c)	5.4	0	(c)

[a] Values are in billions of mid-1981 dollars.

[b] To convert total undiscounted costs to undiscounted costs per kilogram divide by 145,000,000.

[c] Undiscounted costs in perpetuity are undefined.

Table 2-6. Comparative cost evaluation of the waste-management system--HLW disposal

	Total undiscounted cost[a]					
Scenario	At-reactor expansion	MRS	Trans-portation	Repository R&D and overhead	Repository	Total
3A--Disposal with storage at reprocessing facility	2.3	—	3.0	4.1	10.2	19.6
4B--Storage at tunnel-rack MRS facility, 100-year-old waste	2.3	3.2	3.4	8.4	6.2	23.5
4B--Storage at open-field dry-well MRS facility, 100-year-old waste	2.3	3.0	3.4	8.4	6.2	23.3
4C--Disposal with tunnel-rack MRS only	2.3	(b)	(b)	5.4	0	(b)
4C--Disposal with open-field dry-well MRS only	2.3	(b)	(b)	5.4	0	(b)

[a] Values are in billions of mid-1981 dollars.

[b] Undiscounted costs in perpetuity are undefined.

were made for each element that included capital, operating, maintenance, and decommissioning costs where applicable. These costs were estimated based on the requirements of each scenario regarding capacity, lifetime, and handling rates.

In reviewing Tables 2-5 and 2-6, two major differences in scenarios are apparent. The first is the $2.2 billion difference between Scenario 1A and Scenario 1B. This is attributable to the higher costs of smaller at-reactor pool storage facilities that would be required by utilities and the belief that these utilities will conservatively commit to excess storage capacity due to uncertainties about the date when they, individually, will be able to ship spent fuel to repositories, even if these repositories are available in the year 2000. The second major difference, approximately $10 billion, is between Scenario 2A and 2B. This represents costs associated with storing all spent fuel for 100 years in three MRS facilities.

Tables 2-7 and 2-8 display the unit comparison costs in dollars per kgHM when discounted at 3 percent and referenced to the time of reactor discharge as described in Section 2.4.2.1. These costs are comparison numbers that identify cost differences among the scenarios while accounting for the time value of money. They do not represent actual costs to either private utilities or the Federal Government. The underlying cost differences presented in Tables 2-5 and 2-6 are included in these numbers; however, the discounted costs reflect the time of outlay, thus weighting more heavily those costs incurred early than those incurred later. This characteristic always shows lower costs for scenarios where expenditures are deferred until later years. This effect is clearly illustrated in Scenarios 2B, 2C, 4B, and 4C.

2.4.2.4 Sensitivity of results

Additional analyses were performed to examine the sensitivity of the results to selected financial and operational assumptions as follows:

- Discount Rate

  The dollars per kgHM values for various scenarios were found to exhibit different characteristics when the discount rate was varied. In general, the longer substantial costs are deferred, the more sensitive the results are to the discount rate. This can change the relative unit cost for waste management. Figure 2-3 displays this behavior by comparing two different scenarios as a function of Scenarios 1B and 2B versus discount rate.

- Research and Development Cost

  Research and development (R&D) costs are one of the largest contributors to the total discounted waste-management costs. Significant delays in R&D funding or significant reductions in R&D expenditures, as were assumed in MRS scenarios, reduce the total discounted costs (Waddell, 1981a).

Table 2-7. Discounted cost comparison of the waste-management system--spent-fuel disposal[a,b]

Scenario	At-reactor expansion	Away-from-reactors	MRS	Transportation	Repository R&D and overhead	Repository	Total
1A--Disposal with storage at reactor expanded pools	55	—	—	18	32	65	170
1B--Disposal with storage at away-from-reactors	—	22	—	18	33	67	140
2A--Storage at tunnel-rack MRS facility in the year 2000	12[c]	—	19	21	33	66	151
2A--Storage at open-field dry-well MRS facility in the year 2000	12[c]	—	15	21	33	66	147
2B--Storage at tunnel-rack MRS facility, 100-year-old fuel	12[c]	—	32	10	24	4	82
2B--Storage at open-field dry-well MRS facility, 100-year-old fuel	12[c]	—	27	10	24	4	77
2C--Disposal with tunnel-rack MRS only	12[c]	—	34	10	23	—	79
2C--Disposal with open-field dry-well MRS only	12[c]	—	29	10	23	—	74

[a] Values are dollars per kilogram at a discount rate of 3 percent per year. Referenced to time of reactor discharges in mid-1981 dollars.

[b] To convert discounted unit costs to total discounted costs multiply by 89,000,000.

[c] Figure based on distributing cost of at-reactor storage capacity over 145,000 MTHM of spent fuel. True unit cost should be based on 37,000 MTHM.

Table 2-8. Discounted cost comparison of the waste-management system--HLW disposal[a,b]

Scenario	At-reactor expansion[c]	MRS	Trans-portation	Repository R&D and Overhead	Repository	Total
3A--Disposal with storage at reprocessing facility	17	--	12	30	42	101
4B--Storage at tunnel-rack MRS facility, 100-year-old waste	17	11	11	25	3	67
4B--Storage at open-field dry-well MRS facility, 100-year-old waste	17	9	11	25	3	65
4C--Disposal with tunnel-rack MRS only	17	12	11	22	--	62
4C--Disposal with open-field dry-well MRS only	17	10	11	22	--	60

[a] Values are dollars per kilogram at a discount rate of 3 percent per year. Referenced to time of reactor discharges in mid-1981 dollars.

[b] Cost and revenues for reprocessing facility not included in evaluations; assumed to be equal for all scenarios.

[c] Figure based on distributing cost of at-reactor storage capacity over 145,000 MTHM of spent fuel. True unit cost should be based on 37,000 MTHM.

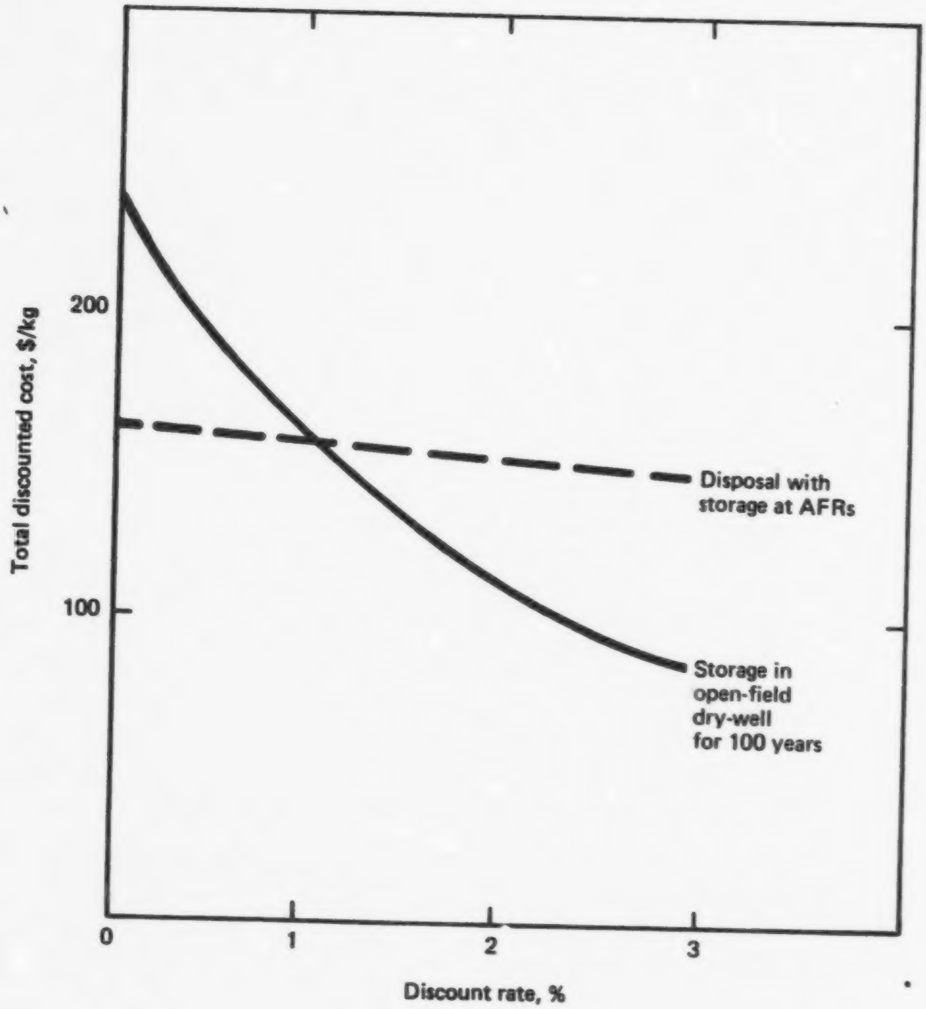


Figure 2-3. Unit cost as a function of discount rate (reference to time of discharge from reactor).

[redacted]

- **Storage Period**

  The results given in the previous discussion for Scenarios 2B and 4B assume a 100-year storage period. Scenarios for a 50-year storage period were also investigated. The results of both analyses are presented in Table 2-9 (Waddell, 1981b). One hundred years storage of spent fuel shows a total discounted cost of $21/kgHM less than the value for 50-year storage. For high-level waste, the cost difference is $12/kgHM. These differences are not a result of the reduction in cost of the program from the disposal of cooler waste, but result from the deferral in cost incurred for the repository.

2.4.2.5 Funding profiles

Figures 2-4 and 2-5 show annual costs to the Government through the year 2000 for Scenarios 1A, 1B, 2B, 3, and 4B. These costs are for repositories, research and development and Government overhead, the Government's share of transportation, MRS facilities, and away-from-reactor facilities.

The funding profiles for Scenarios 1A and 1B show a significant cost increase beyond 1992 reflecting the requirements for the design, licensing, and construction of three repositories. The three repositories are scheduled for operation in the years 2000, 2003, and 2006. The difference between Scenarios 1A and 1B in the 1982 to 1992 time frame reflects the additional funds required for the Government to purchase and build AFR facilities. Funding requirements for Scenario 3 are significantly reduced for two reasons. It is assumed that private industry establishes the reprocessing capability to handle the spent fuel generated by reactors and, with reprocessing, the reduction in the volume of waste requires that only one repository will have to be established in the 2000 to 2006 time period. Scenarios 2B and 4B each show reduced funding requirements because the repository is delayed for 100 years. The funding requirements result primarily from the construction of the MRS facilities and the continuation of the repository siting and R&D program at a reduced level.

2.4.2.6 Summary

The economic analyses reported in Sections 2.4.2.1 through 2.4.2.5 lead to the following conclusions:

1. In general, there is an economic benefit to a few large centralized spent-fuel storage facilities (e.g., AFR or MRS) compared to several smaller at-reactor (AR) pool storage basins. This analysis indicated that an economic benefit could be realized if greater care is given to matching shipping and receiving rates and storage capacities of the facilities in the waste-management system. With a system that had facilities that were more closely

Table 2-9. Discounted cost comparison for disposal of 50-year-old and 100-year-old spent fuel and high-level waste[a]

Parameter	At-reactor expansion	MRS	Trans-portation	Repository R&D and overhead	Repository	Total
50-year-old spent fuel	12	32	14	25	20	103
100-year-old spent fuel[b]	12	32	10	24	4	82
50-year-old high-level waste	17	11	12	25	14	79
100-year-old high-level waste[c]	17	11	11	25	3	67

[a] Values are dollars per kilogram at a discount rate of 3 percent per year. Referenced to time of reactor discharges in mid-1981 dollars.

[b] Corresponds to Scenario 2B.

[c] Corresponds to Scenario 4B.

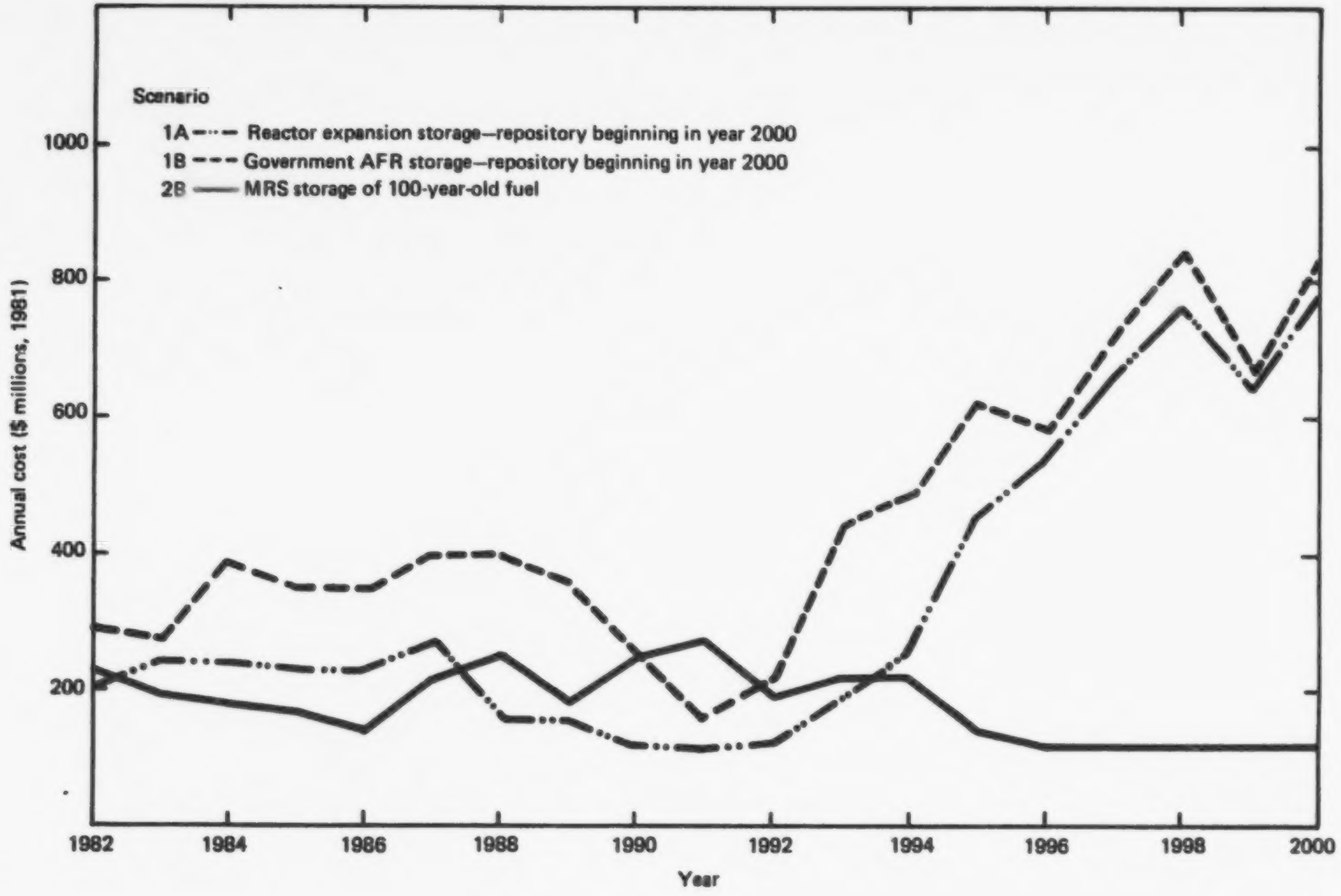


Figure 2-4. Annual Government cost for spent-fuel disposal—1982 to 2000 (mid-1981 dollars in millions).

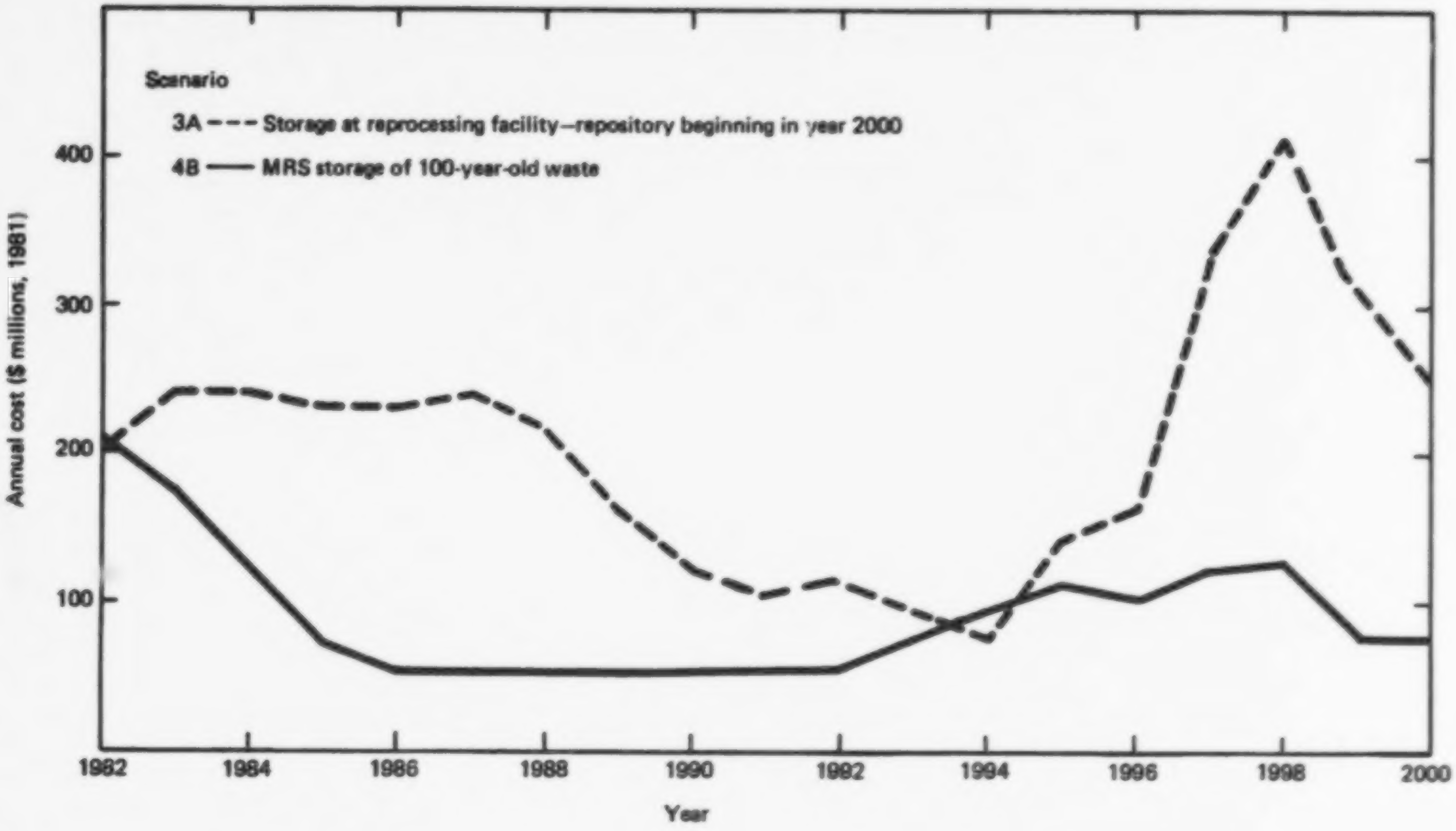


Figure 2-5. Annual Government cost for HLW disposal–1982 to 2000 (mid-1981 dollars in millions)

matched for throughput and storage capacity, the cost differences among Scenarios 1A, 1B, and 2A could be reduced.

2. MRS facilities can be cost competitive with water-basin away-from-reactor facilities as a mode of short-term storage for spent fuels.

3. As a long-term storage system, monitored retrievable storage adds to the cost of waste management in terms of total dollars spent.

4. If future cost are discounted, monitored retrievable storage may offer economic benefits for very long term or permanent storage of spent fuel or high-level waste. These benefits are primarily a result of two factors: (1) an assumed delay in or elimination of expenditures for repositories, combined with (2) the discounting of expenditures made in the future in comparison to present-day cost.

5. If repositories can be delayed for long periods because of a decision to implement a system of MRS facilities, the requirements for Government funding are reduced in the near term.

2.4.3 Public acceptance

This section considers issues related to public acceptance of a total waste-management system that includes monitored retrievable storage as an element. Because this alternative system has not previously been described in any detail to the Nuclear Regulatory Commission, the Congress or the general public, very little direct evidence of public reaction is available. However, previous experiences with similar proposals in the area of nuclear waste management do provide some insight into what reactions might be expected.

The following four basic public acceptance issues concerning waste management were identified by Battelle-Seattle's Human Affairs Research Center (PNL, 1980).

Health and Safety of the Population

Although the health and safety is assumed adequately protected if a facility is licensed by the Nuclear Regulatory Commission, licensing does not ensure public acceptance and the question here is: Will the total waste-management system be perceived as inherently safer with an MRS element than without one?

The work performed to date has not identified any major impacts on health and safety by incorporating monitored retrievable storage into the waste-management system.

It has been shown that deliberate interim storage for periods of 100 years would reduce the thermal load on a geologic repository and, therefore, the temperatures that will be experienced. However, apart from the intuitive feeling that lowering temperatures would be better and the generally recognized fact that chemical and physical reactions probably proceed more slowly at lower temperatures, no definite impact on the total safety of the system has been shown.

Even if a quantifiable improvement in the calculated risk from the facility were to be identified, greater public confidence would not necessarily follow. The series of reactor-cooling experiments conducted by the Nuclear Regulatory Commission in the LOFT reactor have clearly demonstrated large margins of safety in emergency core-cooling systems, and yet no appreciable change in public concerns about the safety of nuclear reactors seems to have taken place.

Public concerns about the safety of nuclear facilities have not been influenced significantly by technical information. Although this situation may be attributable to incomplete dissemination of information to the public, if this continues to be true, a new technical option for waste management, such as monitored retrievable storage, will not contribute to public acceptance even if it were to add to safety.

Survival of Long-Term Institutions

In order for the public to accept monitored retrievable storage, it has to believe that mankind has the ability to form long-term institutions that will (1) manage the waste, (2) transfer information to succeeding generations, (3) maintain continuity of qualified personnel, and (4) provide continuity of funding to cover the cost of permanent disposal.

It seems reasonable to assume that an organization can be developed that is capable of performing the above functions over a 100-year time frame. However, current public confidence in Government agencies will have to improve.

Effect of a Delay in Final Disposal

The MRS long-term storage role could create public concern regarding a permanent solution to the nuclear waste problem if the intensive R&D work on a permanent disposal system is delayed. Public response to the Retrievable Surface Storage Facility (RSSF) in 1974 identified several major issues that were instrumental in the withdrawal of the Draft Environmental Impact Statement and a recommitment by the Government to a program for permanent geologic disposal. A key issue involved public concern that interim storage would detract from the major goal of permanent disposal, and, in fact, might be used indefinitely for economic reasons. If interim storage is implemented as an integral part of the overall waste-management program, it would have to be directly supportive in attaining the ultimate goal of safe, permanent disposal at the earliest possible time.

This characteristic would be preserved if sufficient funds were made available to develop geologic repositories as rapidly as possible even while efforts to provide monitored retrievable storage were going on. If, however, competition for funds significantly reduced the repository program and delayed the qualification of sites, public confidence would likely be lessened.

Public Incentives

Incentives will have to be provided to encourage state and local governments to accept either a permanent repository or a long-term storage facility within their boundaries. The perceived disadvantages of either a monitored retrievable storage system or a permanent repository will have the following common elements:

1. Concerns about radioactive materials.
2. The concentrations of waste from Federal nuclear activities into a small number of locations, raising questions about equity.
3. Transportation of radioactive materials on public highways and railroads.
4. Impact on family and children; even 100 years would extend to great-great-grandchildren.

It appears that required mitigating activities for either long-term repositories or long-term retrievable storage facilities will be very similar, if not identical.

2.4.4 Impact on the waste-management facility requirements

The addition of an MRS component to the radioactive-waste-management system would affect the system in different ways depending on the function that such a storage component is expected to perform.

The various scenarios for the development of the nuclear fuel cycle and the alternative roles for monitored retrievable storage have been analyzed to determine how such storage would affect the total system.

Monitored retrievable storage could provide an alternative for the storage of spent fuel now accumulating at reactor power plants. If no provisions are made to improve the efficiency or utilization of storage capacity at existing reactor pools, and storage is the only fuel cycle activity conducted between now and the end of the century, approximately 37,000 MTHM of at-reactor pool storage capacity would have to be added. The following is a short summary of the potential impact of monitored retrievable storage on at-reactor storage:

1. The construction of a dry AFR storage facility with a capacity of 10,000 MTHM of spent fuel (900 MTHM/yr throughput) by 1990 could reduce the needs for the construction of 12,000 to 24,000 MTHM of spent-fuel at-reactor storage

capacity. Although the total storage capacity would provide storage for all excess spent fuel generated through 1996, a second facility would have to be brought on line in 1992 to accommodate the increasing rate of discharge and a third facility by 1997. The three facilities should be capable of handling the worst situations of reactor overflow through the year 2000. Even with the availability of new storage in 1990, a shortfall of storage capacity of between 860 and 2500 MTHM will still exist. Approximately 740 MTHM of spent fuel could be stored at Morris, Illinois. This indicates that as many as 17 reactors could have difficulty with continued operation.

2. Should the availability of a dry AFR storage facility be delayed until 1995, then two 10,000-MTHM facilities (900 MTHM/yr throughput) would have to become operational together. The reduction in at-reactor pool storage construction would be less than 12,000 MTHM. Delay until 1995 results in a shortfall of storage capacity of between 4500 and 10,000 MTHM. This indicates that as many as 40 reactors could have difficulty with continued operations.

Monitored retrievable storage could be used to cool the waste before disposal. This would mean that the construction of the repository would be delayed by 50 to 100 years depending on the desired reduction in thermal output from the waste. However, an active geologic exploration program would have to be maintained as a basis for finding the site for permanent disposal of the waste. Three MRS facilities of 48,000-MTHM capacity would be required. If spent fuel is stored then they should be available by 1997 primarily to handle the rate of discharge from reactors. If throughput capacity at a single facility could be increased, however, it would be possible to construct three facilities in sequence over a longer period of time. The increase in total program cost for the disposal of spent fuel is approximately 45 percent as a result of the 100-year delay.

The use of these facilities for long-term storage of solidified high-level waste would require that the first facility be in operation by the year 2000 if reprocessing began in 1990. Facilities constructed to store only high-level waste would be smaller than those for storing spent fuel with a reduction in cost of approximately 50 percent. However, additional facilities would also be required for storing transuranic waste. The requirements for such storage have not been estimated. This may be a significant issue since the volume of transuranic waste is 10 times that of high-level waste. The experience of the Department of Energy with the transuranic waste stored in Idaho a is good measure of the sensitivity of this issue.

If monitored retrievable storage were considered acceptable as a replacement for geologic repositories, and if no further use of nuclear power took place beyond the output of 150 gigawatts electric studied here, three facilities with a capacity of 145,000 MTHM could provide indefinite long-term storage. The total cost of this program is unknown because of the requirement to actively manage the material and periodically (100 to 300 years) rebuild the facilities. The acceptability of this approach needs to be carefully evaluated in light of the previous experiences with the proposed Retrievable Surface Storage Facility.

2.5 MRS rationale

The previous sections have discussed potential roles of MRS facilities in the waste-management system with regard to health and safety, cost, and public acceptance. Incorporation of monitored retrievable storage into the waste-management system will depend on the degree to which the addition of such storage would provide clear benefits to safety, cost, public acceptance, siting or technology. A summary discussion of monitored retrievable storage with respect to each of these areas is presented below.

1. Does monitored retrievable storage contribute in a positive way to public health and safety compared to other storage and disposal alternatives?

   This study could not conclusively answer this question. No situations were postulated that would rule out the use of MRS facilities because of health and safety concerns. The possible reduction in temperatures in a geologic repository produced by prior long-term storage of wastes is intuitively thought to improve repository reliability, but no quantitative benefits have yet been substantiated, although it is a generally recognized fact that chemical and physical reactions proceed more slowly at lower temperatures.

2. Is monitored retrievable storage cost effective when compared with other options?

   It appears as if MRS facilities can be cost competitive with water-basin AFR facilities as a mode of storage for spent fuels. Furthermore, as a long-term storage or permanent disposal system, monitored retrievable storage may offer economic benefits. However, the benefits shown result primarily from a delay in repository timing or replacement of repositories by MRS facilities combined with the discounting of the value of delayed investments.

3. Can MRS improve public confidence in the Government's ability to safely handle and dispose of nuclear waste?

   Further analysis and testing of public opinion would be required to obtain a clear answer to this question. The consideration of previous public reaction suggests that the substitution of a perceived "interim solution" to waste management will lessen public confidence. Improvement in the technical understanding of the safety of nuclear reactors does not seem to have led to increased public acceptance of nuclear reactors and therefore technical benefits in waste-management systems which have not been thoroughly communicated to the public may not improve public acceptance either.

4. Can MRS be more easily sited than other waste storage or disposal facilities?

   MRS facilities may be able to be located in more areas of the United States than deep geologic repositories because technical requirements are less demanding. However, it does not therefore follow that they will be easy to site or easier to site than other interim centralized storage facilities.

5. Is the technology available to site, design, construct, and operate an MRS facility?

   Some MRS concepts have been demonstrated on a small scale, such as vaults, dry wells and storage silos. Other concepts, such as casks-in-trench and tunnel-rack storage, have not been tested. No concept has been licensed. In general, the technology exists but some further research and development will probably be required before moving forward with an MRS facility.

In summary, knowledge about the design, costs, site suitability, and licensability of an MRS are still limited. Until more is known about these areas, a firm rationale for incorporating long-term monitored retrievable storage into the waste-management system is not available.

References for Chapter 2

DOE (U.S. Department of Energy). 1979. Technology for Commercial Radioactive Waste Management. DOE/ET-0028, Vol. 4, Washington, D.C.

DOE (U.S. Department of Energy). 1980a. Statement of Position of the United States Department of Energy - Proposed Rulemaking on the Storage and Disposal of Nuclear Waste. DOE/NE-0007, Washington, D.C.

DOE (U.S. Department of Energy). 1980b. Report on Fee for Spent Nuclear Fuel Storage and Disposal Services. DOE/SR-0006, Aiken, S.C.

DOE (U.S. Department of Energy). 1980c. DOE Study on Spent Nuclear Fuel Storage. DOE/SR-004, Aiken, S.C.

DOE (U.S. Department of Energy). 1980d. Spent LWR Fuel Storage Costs: Reracking AR Basins and AFR Basins. DOE/SR-SF-2002, Rev. 1, Aiken, S.C.

Dupont. 1978. Conceptual Design Report for the Away-from-Reactor Spent Fuel Storage Facility, Savannah River Plant. DPE-3547, Aiken, S.C.

Fishback, D. 1981. Virginia Electric and Power Company. Personal Communication to R. P. Morisette, General Atomic Company.

General Atomic Company. 1981. Monitored Retrievable Storage Concept Definition and Evaluation Report. GA-A16424, San Diego, Calif.

Hamond, R. P. 1979. "Nuclear Waste and Public Acceptance." American Scientist, Vol. 67, pp. 146-150.

IAEA (International Atomic Energy Agency). 1981. Cost of Spent Fuel Management. Vienna, Austria.

MRS Cost Comparison Working Group. 1981. Derivation of Alternate Monitored Retrievable Storage Cost Comparison from Original Estimates. Letter (September 18, 1981) to Dr. D. K. Vieth, U.S. Department of Energy.

NRC (U.S. Nuclear Regulatory Commission). 1980a. Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation. 10 CFR 72, Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission). 1980b. Dry Storage of Spent Nuclear Fuel. A Preliminary Survey of Existing Technology and Experience. NUREG/CR-1223, Washington, D.C.

ONWI (Office of Nuclear Waste Isolation). 1979. An Assessment of LWR Spent Fuel Disposal Option. ONWI-39, Vol. 3, Columbus, Ohio.

ONWI (Office of Nuclear Waste Isolation). 1980. Projected Cost for Deep Geologic Repositories for Spent Fuel Disposal. ONWI-191, Columbus, Ohio.

Plesset, M. S. 1980. ACRS Comments on Proposed Rulemaking on the Storage and Disposal of Nuclear Waste. Letter (December 10, 1980) to John F. Ahern, U.S. Nuclear Regulatory Commission.

PNL (Pacific Northwest Laboratories). 1978. Nontechnical Issues on Waste Management; Ethical, Institutional and Political Concerns. PNL 2400, Richland, Wash.

Rickertsen, L. 1980. Repository Thermal Energy for the Management of Commerically Generated Radioactive Wastes. Letter (April 23, 1980) to Robert McKee, Pacific Northwest Laboratories.

TVA (Tennessee Valley Authority). 1979. Spent Fuel Management Program Study - Summary Report. Chattanooga, Tenn.

Waddell, J. 1981a. *R&D Cost for the NWTS Program With and Without Monitored Retrievable Storage*. Letter (September 24, 1981) to Dr. D. L. Vieth, U.S. Department of Energy.

Waddell, J. 1981b. *Repository Cost Savings Resulting from Aging Waste*. Letter (September 23, 1981) to Dr. D. L. Vieth, U.S. Department of Energy.

Westinghouse Electric Corporation. 1981. Conceptual Design Evaluation Study for Interim Off-Site Spent Fuel Storage Installation. WI 81-176, Pittsburgh, Penn.

3 Area/Location Screening

3.1 Introduction

One of the principal technical features of the monitored retrievable storage (MRS) system is that a hermetically sealed container, not the geology, would be the primary means of containment of the radionuclides over the limited storage period; this feature allows the packages to be readily retrievable. The primary function of the geology is to provide the protection of the package. This chapter addresses the question posed in Chapter 1, namely, where would MRS facilities be located?

It has been suggested (Hammond, 1979) that, because of the temporary nature of monitored retrievable storage and the requirement that the package be totally under the control of man, an MRS system could be located in almost any state in the continental United States. However, concerns have been expressed about the impact of natural degradation processes on the containment package and about the licensing requirements that will have to be met for siting locations where highly radioactive materials will be stored. Furthermore, if monitored retrievable storage were to be adopted for long-term use, several facilities in different regions of the country might be required to handle the quantities of material involved.

An effort was undertaken to propose a set of general criteria that could be used for screening areas in the contiguous 48 states that would have favorable characteristics for an MRS facility. Because of the time limits of this study and the requirement of uniform data for the evaluation, it was not the intention of this study to identify all acceptable areas for an MRS facility in each state. Rather, the objective of this screening work was to identify areas in the contiguous 48 states that would have a high likelihood of containing a high density of favorable sites.

3.2 Technical approach

This study was performed to identify areas or locations that might be suitable for an MRS facility. Such a study has not been done previously.

The screening process of this study for identifying areas or locations was to separate lands that have a higher likelihood of containing favorable characteristics for an MRS site from the total land of the 48 contiguous states. The screening was conducted by applying a set of judgment standards and screening specifications to information concerning the 48 contiguous states. This screening process was used for both the tunnel and surface storage concepts. Existing abandoned mines located within the identified areas were also examined for their suitability as MRS sites.

The screening process did not consider the possibility of engineering measures to alleviate minor problems nor take into account special knowledge of an area that would indicate its suitability for an MRS facility. Only publicly available information that could be uniformly applied at a national scale was used.

The area or location screening was not intended to inventory all suitable sites in each of the 48 states. Instead, conservative screening specifications were used to reduce the geographic area and focus attention on areas containing a high density of favorable sites.

3.2.1 Screening process

The screening process was divided into two phases--national screening and detailed screening. The specifications used for the national screening could be uniformly applied to the entire United States so that the 48 states could be evaluated equally. Additional screening specifications were applied to the remaining areas during the detailed screening. In general, this second step used more detailed information that was available on a regional or state-by-state basis.

Using this screening process, areas that met all of the specifications were identified as having a high likelihood of containing desirable areas for an MRS facility. Although areas eliminated by the screening process may also contain favorable sites, the remaining areas are likely to have a higher density of favorable locations for an MRS facility. Areas or locations remaining after the detailed screening were also screened for existing abandoned mines that might be considered for the tunnel storage concept.

A sensitivity analysis was conducted by considering the effects of varying selected specifications used in the national screening in order to investigate the implications of the assumptions made. During this analysis, several screening specifications were varied to determine the extent to which the screening results are dependent on these specifications.

3.2.2 Limitations

With such a screening process, many locations would be eliminated from further consideration in the screening process although they would actually be acceptable. For example, one of the screening specifications for the tunnel concept was to include areas where granite and other intrusive igneous rocks plus medium- to high-grade metamorphic rocks and shales of sufficient size are shown on national geologic maps; areas meeting this specification should include desirable locations for a tunnel or mined facility. However, other types of rocks might have locally favorable characteristics that make them acceptable for a facility, or there may be small isolated outcroppings of granite and other intrusive igneous rocks plus medium- to high-grade metamorphic rocks and shale that could be acceptable for a facility that are not large enough to appear on national geologic maps. Because of the assumptions made to allow clear focus on areas that have a high probability of containing favorable sites, it was expected that the identification of the land area that might be suitable would be biased toward the low side.

3.3 Screening specifications

The screening specifications used for this assessment were selected by considering environmental, geologic, and licensing factors. The environmental factors are those that would impact the long-term durability of the container, such as surface-water and ground-water conditions. The geologic factors are those features that affect the protection of the container and affect conventional engineering structures, such as ground-motion and fault rupture. The regulatory licensing factors are those historically established guidelines and specifications for the nuclear industry, such as 10 CFR 72 and other health- and safety-related regulatory requirements (NRC, 1975, 1977, 1980a,b, 1981).

The screening specifications were selected by first identifying generally relevant issues that needed to be addressed for the environmental, geologic, and regulatory licensing factors. Specific considerations needed to adequately address each issue were then determined. Next, one or more measures that could be used to describe the adequacy of an area with respect to each consideration were selected. Finally, a screening specification was selected for each measure.

The issues, considerations, measures, and specifications for both the national and detailed screening are presented in Table 3-1. Because the facility characteristics for tunnel storage differ from those for surface storage in ways that affect the relative desirability of some areas as sites, some of the screening specifications are different. The rationale for each element is shown in italics in Table 3-1. For example, for the tunnel storage concepts, one of the relevant issues is area or location geometry. Adequate extent and depth is required for proper placement of the facility. The adequacy of the geometry can be evaluated by considering the depth, lateral extent, and surface character of an area. These must be considered because the facility should be located in an area that has enough lateral extent for facility layout and a buffer zone. The area should also have enough depth to allow protection from active weathering, soil formation, and impact of surface activities. The topography should allow horizontal or gently inclined access. The thickness of host rock units was used as a measure because there is uniform information available at the national scale. Rock units were used as a screening specification because tunnel construction and stability require a "competent" rock.

For the surface storage concepts, hydrogeology is important since it would affect the construction, the operation of the facility, and waste containment and retrieval. The major considerations of

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a]

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
		Applicable only to tunnel concepts (rack, dry well, and inactive mines)			
T1 AREA/LOCATION GEOMETRY	T1.1 DEPTH OF THE FACILITY HORIZON	Thickness of host rock units	Include areas with granite and other igneous rocks plus medium- to high-grade metamorphic rocks and shale of sufficient size to be shown on national geologic maps[b]	Thickness of host rock units	Include areas with granite and other igneous rocks plus medium- to high-grade metamorphic rocks and shale of sufficient size to be shown on state geologic maps[b]
Adequate geometry is required for facility placement	*The facility should be located sufficiently below the zone of active weathering, soil formation, and impact of surface activities*	*This measure has uniform information available at a national scale*	*Rock units mapped at a national scale have sufficient thickness*	*This measure has uniform information available at a detailed, or regional, scale*	*Rock units mapped at a detailed scale have sufficient thickness*
	T1.2 LATERAL EXTENT			Minimum lateral dimensions of locally acceptable area for a tunnel or mined facility	Include areas with minimum lateral dimensions of 3 by 3 miles not otherwise screened out
	Sufficient lateral extent should be available to accommodate the facility and a buffer zone and allow some flexibility in orienting and laying out the facility			*Self-explanatory*	*The maximum lateral dimensions of currently proposed tunnel facilities are approximately 1.5 miles. This screening specification allows flexibility in orientation and a buffer zone*
	T1.3 SURFACE CHARACTER	Topography	Include areas where either (1) more than 20% of the land surface has greater than 8% (4°35') slope and the local relief is greater than 500 feet; or (2) more than 50% of the land surface has greater than 8% slope and the local relief is greater than 300 feet[c]	Slope	Include areas that have 500 feet of relief within a 9-square-mile (3 by 3 miles) area
	The tunnel facility design is specified to have horizontal or gently inclined access	*Self-explanatory*	*This specification corresponds to data available on a uniform national basis at the required scale; 8% was arbitrarily chosen as the upper limit for a "gentle" slope*	*Self-explanatory*	*This specification identifies locally flat areas that were not determined by the national screening; 500 feet is the contour interval on many of the maps used for detailed screening*

Note: See footnotes at end of table.

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a] (Continued)

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
Applicable only to tunnel concepts (rack, dry well, and inactive mines) (continued)					
T2 HYDROGEOLOGY	T2.1 HYDROGEOLOGIC CHARACTERISTICS	Rock type	Include areas containing rock with low permeability, effective porosity, hydraulic gradient, and fracture spacing (i.e., granite and other igneous rocks plus medium- to high-grade metamorphic rocks and shale) identifiable on national geologic maps	Surface drainage	Include areas outside lakes, playas, rivers, and floodplains identifiable on regional maps[d]
The hydrogeologic regime in which the facility is located should have characteristics compatible with facility operation and waste containment and retrieval	*See Issue*	*This measure uses rock properties to assess hydrogeologic characteristics compatible with facility operation and waste containment and retrieval*	*These rock types have generally favorable hydrogeologic characteristics*	*Locating a facility in areas with undesirable surface drainage would result in construction and operation complexities*	*Lakes, playas, rivers, and floodplains are areas of undesirable surface drainage*
	T2.2 GROUND-WATER SYSTEM	Principal aquifers[e]	Include areas outside principal aquifers[e]		
	The ground-water system provides an important path to the biosphere for radionuclides in the event that facility containment fails	*Principal aquifers provide much of the municipal and agricultural water currently or potentially used*	*See Measure*		
	T2.3 KARST TOPOGRAPHY			Rock type	Include noncarbonaceous rocks
	Karst conditions can substantially complicate facility construction			*This measure uses the dissolution characteristics of carbonaceous rocks to identify locations of present or potential collapse and subsidence of rock mass and undetermined ground-water flow caused by karst conditions*	*Karst conditions occur in carbonaceous rocks*

Note: See footnotes at end of table.

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a] (Continued)

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
		Applicable only to surface concepts (dry wells, casks, and vaults)			
S1 AREA/LOCATION GEOMETRY	S1.1 LATERAL EXTENT			Minimum lateral dimensions of locally acceptable area for a surface facility	Include areas with minimum lateral dimensions of 3 by 3 miles not otherwise screened out
Adequate geometry is required for facility placement	*Sufficient lateral extent should be available to accommodate the facility and a buffer zone, and allow some flexibility in orienting and laying out the facility*			*Self-explanatory*	*The currently proposed surface facilities have lateral dimensions of approximately 2 by 2 miles. This screening specification allows some flexibility in layout*
	S1.2 SURFACE CHARACTER	Topography	Include areas where either (1) at least 50% of the land surface has less than 8% (4°35') slope, or (2) at least 20% of the land surface has less than 8% slope and local relief is less than 500 feet[c]	Slope	Include areas that have less than 500 feet of relief within a 9-square-mile (3 by 3 miles) area
	Construction and operation of a surface facility would be aided by flat or gently sloping terrain	*Self-explanatory*	*This specification corresponds to data available on a uniform national basis at the required scale; 8% was arbitrarily chosen as the upper limit for a "gentle" slope*	*Self-explanatory*	*This specification identifies locally hilly areas that were not determined by the topography measure in the national screenings; 500 feet is the minimum contour interval on many of the maps used for detailed screening*
S2 HYDROGEOLOGY	S2.1 SURFACE HYDROLOGICAL CHARACTERISTICS			Surface drainage	Include areas outside lakes, playas, rivers, and floodplains identifiable on regional maps[d]
The hydrogeologic regime in which the facility is located should have characteristics compatible with facility operation and waste containment and retrieval	*See Issue*			*Location of a facility in areas with undesirable surface drainage would result in construction and operation complexities*	*Lakes, playas, rivers, and floodplains are areas of undesirable surface drainage*

Note: See footnotes at end of table.

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a] (Continued)

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
Applicable only to surface concepts (dry wells, casks, and vaults) (continued)					
	S2.2 GROUND-WATER SYSTEM	Principal aquifers[e]	Include areas outside principal aquifers[e]	Ground-water table	Include areas except where the minimum depth to ground water is less than 100 feet below land surface based on available data
	The ground-water system provides an important path to the biosphere for radionuclides in the event that facility containment fails	*Principal aquifers provide much of the municipal and agricultural water currently or potentially used*	*See Measure*	*Construction, operation, and retrieval for a surface facility would be more complex if the ground-water level were above the base of the facility wells*	*This specification allows some buffer below the base of the facility wells in currently proposed designs*
	S2.3 KARST TOPOGRAPHY			Rock Type	Include noncarbonaceous rocks
	Karst conditions can substantially complicate facility construction			*This measure uses the dissolution characteristics of carbonaceous rocks to identify locations of present or potential collapse and subsidence of rock mass and undetermined ground-water flow caused by karst conditions*	*Karst conditions occur in carbonaceous rocks*
Applicable to both concepts					
3 TECTONIC ENVIRONMENT	3.1 FAULT RUPTURE			Distance from faults interpreted to be capable	Include areas greater than 5 miles from both (1) known faults interpreted to be capable and (2) known faults whose capability is unknown and that have low potential for a capable evaluation
The facility should be located such that credible tectonic phenomena will not degrade system performance below acceptable limits	*Fault rupture could lead to conditions outside the design basis of the facility and hence to failure of waste containment*			*See Consideration*	*NRC regulations and construction safety codes require special detailed studies for facilities not meeting this specification*

Note: See footnotes at end of table.

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a] (Continued)

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
		Applicable to both concepts (continued)			
				Distance from known faults interpreted to be not capable	*Include areas except (1) faults interpreted to be not capable and (2) faults whose capability is unknown but that have a high potential for a capability evaluation*
				Such faults pose engineering difficulties and provide a pathway to the biosphere for radionuclides in the event that containment fails	*Self-explanatory*
	3.2 GROUND MOTION	Locations with respect to potential earthquake sources and estimated levels of ground motion	Include areas with at least a 95% probability that the peak surface acceleration in rock within a period of 130 years from known and interpreted earthquake sources will be less than 0.2g	Location with respect to potential earthquake sources and estimated levels of ground motion	Include areas that are both (1) more than 12 miles from felt epicenters of greater than MM V and (2) greater than 6 miles from instrumental epicenters of greater than magnitude 4.0 that occur in clusters, as interpreted from historical earthquake epicenter plot maps
					Include areas more than 6 miles from both (1) isolated earthquakes of epicenter intensities greater than MM V and (2) isolated earthquakes of greater than magnitude 4.0 based on estimated location and geologic tectonic setting
	Excessive ground motion could lead to conditions outside the design basis of the facility, and hence to failure of waste containment	*See Consideration*	*The design basis of the MRS facility is 0.25g; the specification of 0.2g is the closest level for which uniform national data are available. The projected approximate facility life is 130 years,[f] including loading, storage, and retrieval. The relatively liberal 95% probability criterion is used because of the generalized and approximate nature of available national data*	*See Consideration*	*This specification has been used in past siting studies for nuclear facilities to avoid areas where local conditions might result in excessive ground motion and potential failure of waste containment*

Note: See footnotes at end of table.

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a] (Continued)

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
		Applicable to both concepts (continued)			
	3.3 VOLCANIC EFFECTS	Distance from Quaternary volcanic sources and their processes	Include areas outside both (1) Quaternary volcanic centers and lava flows and (2) where 75% to 80% of volcanic ash and debris are expected to fall		
	Volcanic effects could result in substantial operational and retrieval difficulties and might also lead to failure of waste containment	*Quaternary volcanic areas have been the location of most historical volcanic activity*	*This specification delineates areas of volcanic explosion, lava flows, and airborne debris and corresponds to information available on a uniform national basis*		
4 HUMAN INTRUSION	4.1 NATURAL RESOURCE EXPLORATION AND EXTRACTION	Location with respect to exploitable energy-related deposits	Include areas outside exploitable oil, gas, anthracitic and coking coal, and geothermal areas	Location with respect to other mineral deposits	Include areas at least 1 mile from existing and potentially exploitable metallic and nonmetallic mineral deposits
The facility should be located to minimize interference with other activities that might lead to inadvertent human intrusion	*Activities related to natural resources have the potential for leading to human intrusion*	*Energy-related resources are the principal natural resources that have sufficient areal extent to be considered in the national screening*	*The listed resources are those with sufficient economic value that there is significant likelihood of human intrusion*	*This measure examines resources not already addressed in the national screening*	*The 1-mile setback provides for future expansion of exploration and exploitation activities*
5 INTERFERING OPERATIONS	5.1 NEARBY INSTALLATIONS	Location with respect to potentially hazardous operations	Include areas outside major military installations	Location with respect to potentially hazardous operations	Include areas more than 5 miles from major industrial and transportation installations
Locating the facility away from hazardous operations will simplify construction and operation	*Most significant risks caused by hazardous operations result from fixed installations*	*See Consideration*	*Military installations are the only installations of sufficient size to be considered in the national screening*	*See Consideration*	*The setback is in accordance with NRC recommendations for siting nuclear reactors*
6 DEMOGRAPHY	6.1 POPULATION CONCENTRATIONS	Population density	Include areas more than 30 miles from counties where the population density is greater than 500 persons per square mile	Distance from population centers	Include areas more than 4 miles from limits of cities containing more than 25,000 people

Note: See footnotes at end of table.

Table 3-1. Screening issues, considerations, measures, specifications, and rationale[a] (Continued)

Issue	Consideration	National screening		Detailed screening	
		Measure	Specification	Measure	Specification
Applicable to both concepts (continued)					
The facility should be located to minimize potential risk to and potential conflict with nearby population	*See Issue*	*Population density is a measure of population concentration that can be used at the scale of the national screening*	*The NRC recommends that the average population density along any 30-mile radius from a nuclear reactor be less than 500 persons per square mile; density data are available only on a county basis within the time frame of this study*	*See Issue*	*This specification is in accordance with NRC recommendations for siting nuclear reactors*
7 ENVIRONMENTAL PROTECTION	7.1 ENVIRONMENTAL IMPACTS	Proximity to Federal areas receiving special land-use protection	Include areas outside national park, national wildlife refuge, and national wilderness preservation systems	Proximity to state areas receiving special land-use protection	Include areas outside individual state comprehensive natural area systems
Numerous Federal and state laws require that environmental protection be taken into account	*See Issue*	*See Issue*	*The categories listed in this specification cover the major areas of interest in Federal laws and regulations*	*See Issue*	*This specification covers the categories of major interest in Federal and state laws and regulations*

Source: Woodward-Clyde Consultants, 1981.

[a] Rationale is stated in italics.

[b] The specific rock types included in this specification are the result of consideration T2.1 (hydrogeologic characteristics) and other factors such as excavatability and retrievability.

[c] Local relief is defined as the maximum difference in elevation within a unit square 6 miles across.

[d] Floodplains are identified by topographic relief and spatial relation to rivers.

[e] Principal aquifers indicate areas underlain by one or more aquifers generally capable of yielding to a well at least 50 gallons per minute (3.5 liters per second) of fresh water.

[f] The probability and time for the ground motion was recalculated from the data of Algermissen and Perkins, 1976.

this issue are surface hydrogeologic characteristics, ground-water system, and karst topography. The surface hydrogeologic consideration can be measured by surface drainage conditions; locating a facility in areas with undesirable surface drainage would result in difficulties in construction and operation. Therefore, the screening specification for surface drainage is to exclude the locations of rivers, lakes, playas, and floodplains.

Ground-water conditions within an area or location are of major concern because the migration of radionuclides in ground water could become a pathway for release to the biosphere should the primary containment fail. In addition, excessive moisture around containment systems located near to the surface and within the biosphere could accelerate degradation leading to the release of radionuclides. The screening specification should therefore be based on the location of shallow, unconfined aquifers within the proposed zone of a surface storage facility. Information on aquifer systems describing their depth is not available on a nationwide basis. However, the locations of principal aquifers (those capable of yielding to a well at least 50 gallons per minute of potable water) are known through the U.S. Geological Survey WATSTORE computer data base for ground-water information at the state level (USGS, 1981). The presence of principal aquifers was therefore used as a screening specification.

Karst conditions could substantially complicate the construction of an MRS facility. Rock type was used as a measure and screening specification. The dissolution characteristics of carbonaceous rocks were used to identify locations of present or potential collapse and the subsidence of rock mass and undetermined ground-water flow caused by karst conditions.

Some potentially relevant factors were not considered in this study. Table 3-2 lists a variety of site-related factors and the explanations of why they were not used.

All information used in the screening process and sensitivity analysis was obtained from published and open file sources, which included publications, maps, and computerized data files of Federal and state agencies, universities, and research institutions.

3.4 National screening

Overlay maps were prepared for each national screening specification. These maps were combined to identify areas that met all of the specifications. Areas identified from the national screening were used for further study during the second, or detailed, screening phase. The results of the national screening for the tunnel and surface facilities are illustrated in Figures 3-1 through 3-4.

The geographic distribution of potentially favorable locations for the tunnel facility includes 25 states, with large locations in Maine, New Hampshire, Vermont, and New York. Moderate-sized

Table 3-2. Factors considered but not used in the screening study

Factor	Reason for not using
Hydrologic flow modeling, hydrologic-geochemical transport-reaction modeling, geochemical properties of surrounding rock	The period of operation for an MRS facility is too short for these to be significant factors, and prediction of geologic phenomena is not important in this period. For the MRS facility, the canister provides containment and, with proper facility design, the geochemical properties of surrounding rock, including sorptive properties, should not be significant to contain and isolate the wastes.
Thermal properties of surrounding rock	The thermal loading imposed by an MRS facility is expected to be low. The age of the waste and the packing and areal density of canisters are to be considered in facility engineering design. These facility specifications are not available at the time of this study.
Subsurface rock dissolution, uplift and subsidence, erosion and denudation, climatic shifts and glaciation	The period of operation for an MRS facility is too short for these factors to be significant.
Extreme natural phenomena	The incidence of extreme natural phenomena is often determined by local conditions that must be studied at a more detailed level than is considered in this study.
Flooding	Areas of surface drainage, including lakes, playas, and floodplains identified on 1:2,500,000 or 1:500,000 scale maps, have been eliminated. More detailed floodplain and flood-level information, such as 100- or 300-year flood levels, should be evaluated on a site-specific basis for specific proposed MRS facility sites.
Waste transportation	This factor requires a greater level of detail than could be considered in this study.
Socioeconomic impacts	The nature and extent of the socioeconomic impacts of constructing and operating an MRS facility depend on details of design, schedule, and operating procedures that have not yet been determined. Generally, these impacts are at a more specific geographic level of detail than is considered in this study, and many of them can be managed by proper mitigation measures.
Land-use conflicts and land ownership	Land-use and land-ownership issues generally involve a more specific geographic level of detail than could be considered in this study, with the exception of the issues considered under environmental protection.
Local public acceptance	The consideration of this factor is outside the scope of this study.

Source: Woodward-Clyde Consultants, 1981.

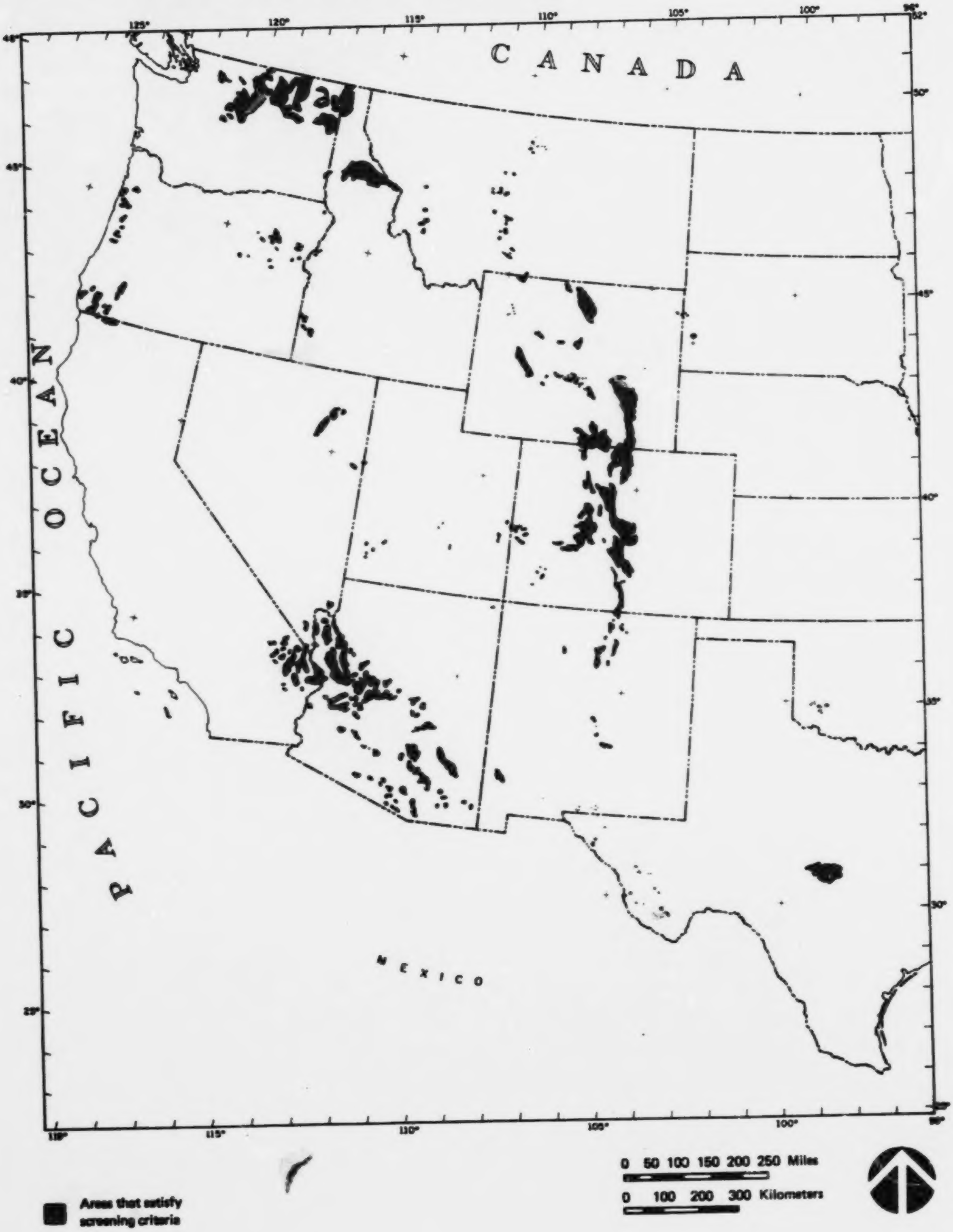

CANADA
PACIFIC OCEAN
MEXICO
125°
120°
115°
110°
105°
100°
95°
50°
45°
40°
35°
30°
25°
0 50 100 150 200 250 Miles
0 100 200 300 Kilometers
Areas that satisfy screening criteria

Figure 3-1. National screening results, MRS tunnel facility, western United States.

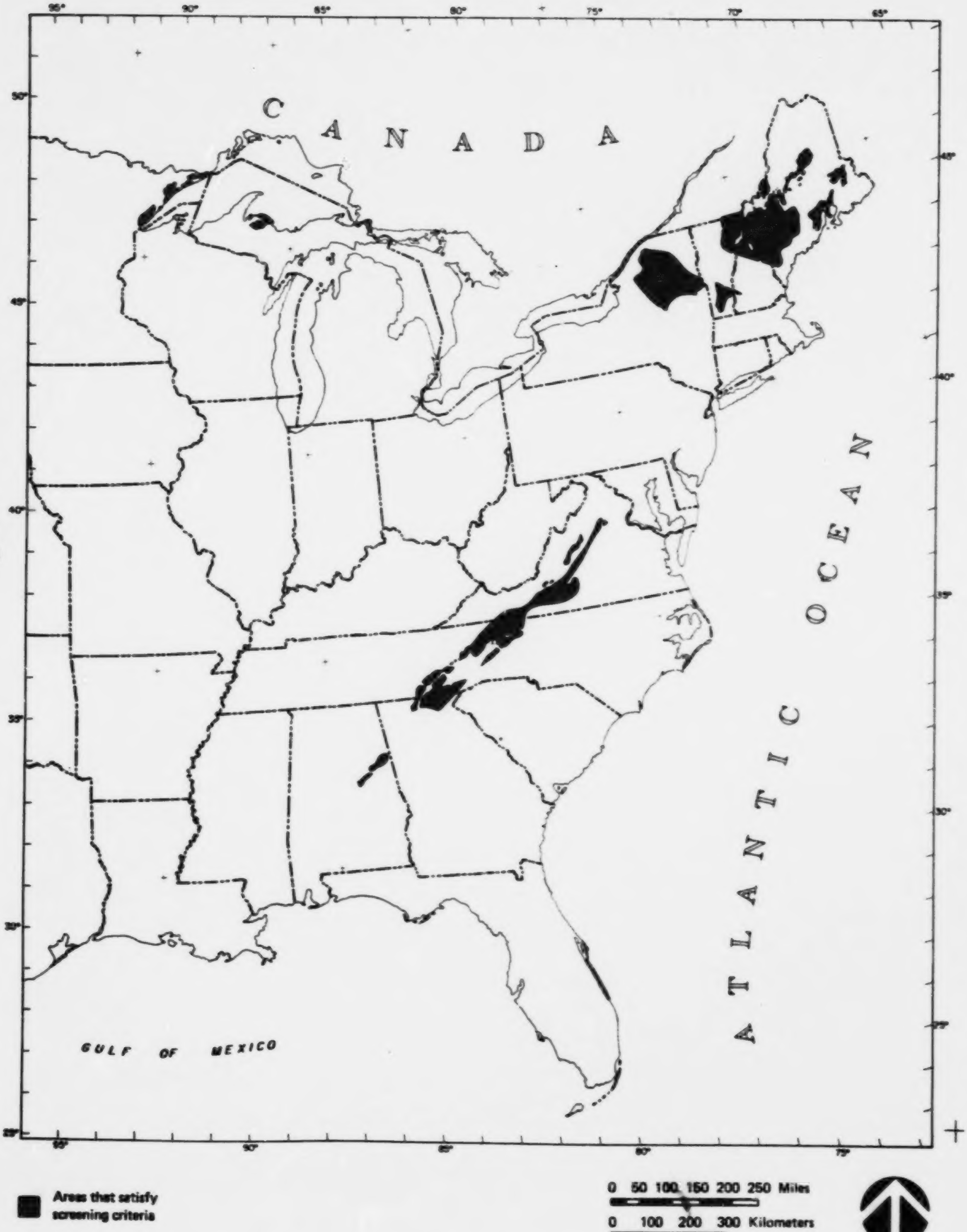

CANADA
ATLANTIC OCEAN
GULF OF MEXICO
95°
90°
85°
80°
75°
70°
65°
50°
45°
40°
35°
30°
25°
■ Areas that satisfy screening criteria
0 50 100 150 200 250 Miles
0 100 200 300 Kilometers

Figure 3-2. National screening results, MRS tunnel facility, eastern United States.

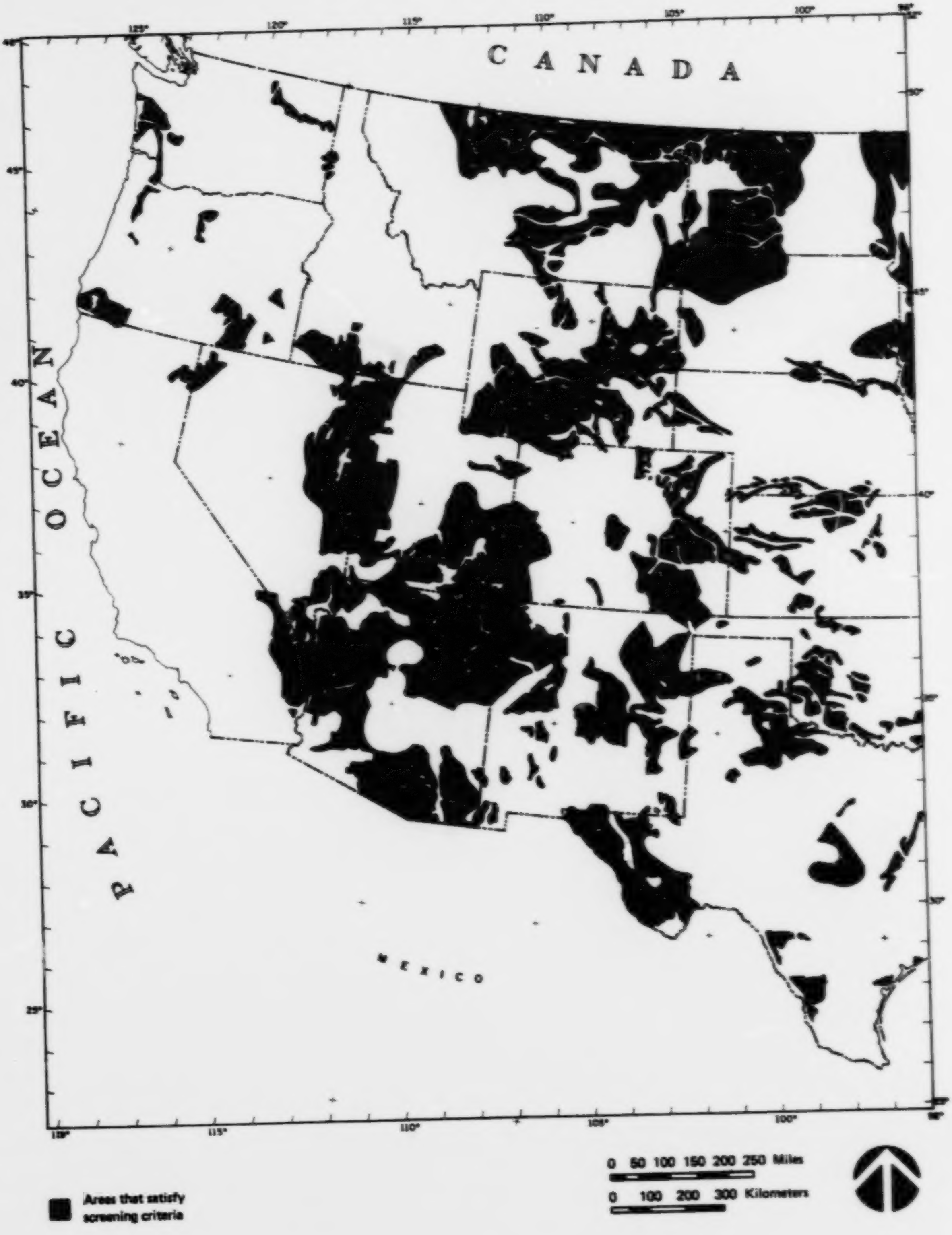

CANADA
PACIFIC OCEAN
MEXICO
125°
120°
115°
110°
105°
100°
95°
45°
40°
35°
30°
25°
0 50 100 150 200 250 Miles
0 100 200 300 Kilometers
■ Areas that satisfy screening criteria

Figure 3-3. National screening results, MRS surface facility, western United States.

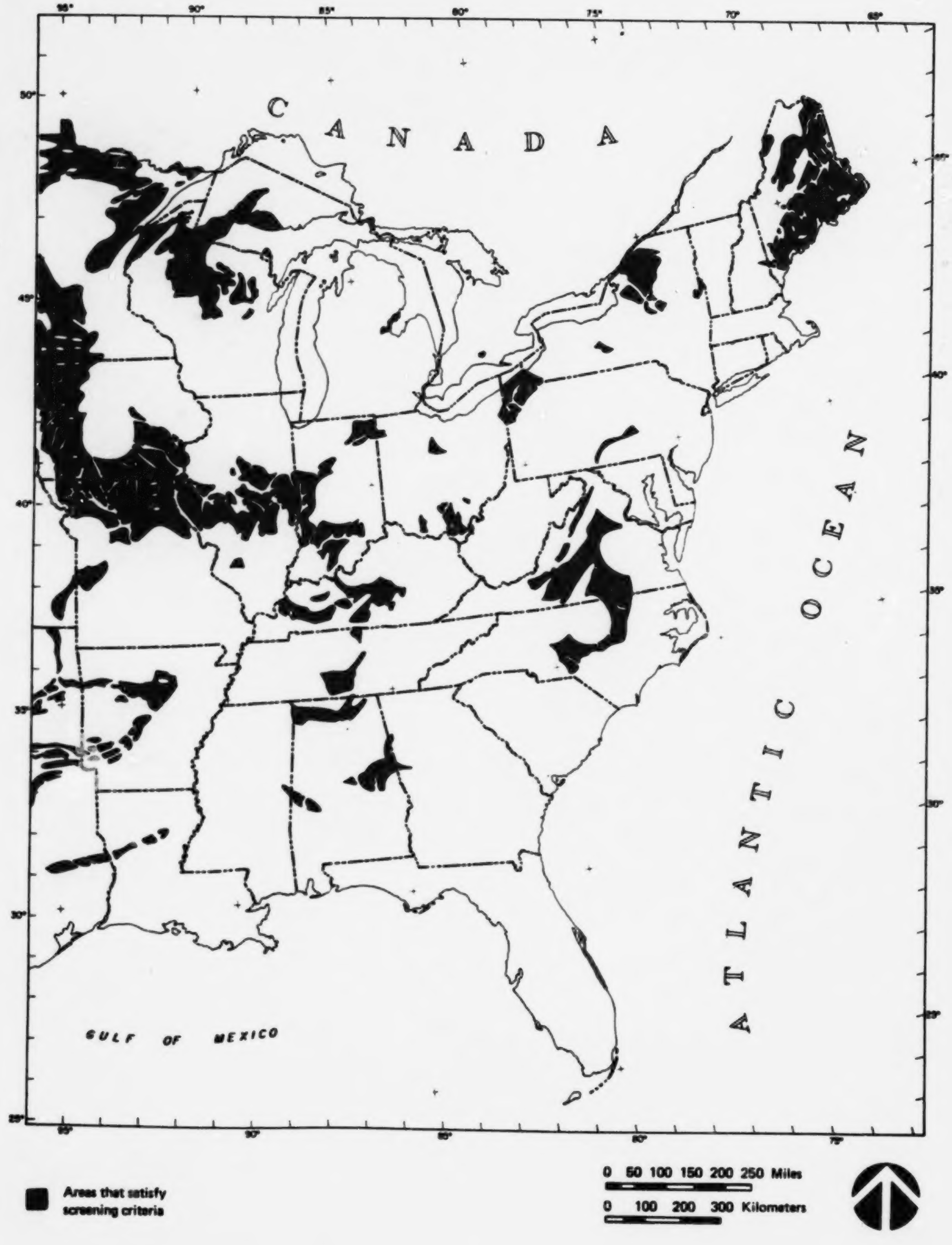

95°
90°
85°
80°
75°
70°
65°
50°
45°
40°
35°
30°
25°
CANADA
ATLANTIC OCEAN
GULF OF MEXICO
■ Areas that satisfy screening criteria
0 50 100 150 200 250 Miles
0 100 200 300 Kilometers

Figure 3-4. National screening results, MRS surface facility, eastern United States.

potential locations are in Virginia, North Carolina, Georgia, Wyoming, Colorado, Arizona, and Washington. Locations of limited size are in Alabama, Michigan, Minnesota, Tennessee, Texas, Montana, New Mexico, Idaho, Utah, Oklahoma, South Dakota, Oregon, Nevada, and California. The total area is approximately 60,500 square miles or 2 percent of the land of the 48 states. A typical tunnel MRS facility would occupy about 2 to 4 square miles.

This distribution is chiefly attributable to the application of rock type, topography, and principal aquifer screening specifications. On the basis of available national-scale data (King and Berkman, 1974), less than 30 percent of the area in the 48 states has rock type and topography that meet the screening specifications.

The national screening for surface facilities identified large potential areas in 40 states that included Maine, Virginia, Illinois, Minnesota, Iowa, Missouri, North and South Dakotas, Montana, Wyoming, Colorado, New Mexico, Utah, and Arizona. Moderate-sized potential locations are in Indiana, Kentucky, Wisconsin, Arkansas, Oklahoma, Texas, and Nevada. Locations of limited size are in New Hampshire, Vermont, New York, Pennsylvania, North Carolina, Ohio, West Virginia, Tennessee, Georgia, Alabama, Michigan, Mississippi, Louisiana, Nebraska, Kansas, Idaho, Washington, Oregon, and California. The total area is approximately 605,000 square miles or 20 percent of the 48 states. A typical surface MRS facility occupies less than 4 square miles.

These results are chiefly attributable to the application of the principal aquifer screening specification since more than half of the nation is underlain by the principal aquifers (USGS, 1970). Other contributing screening specifications included energy resources, ground-motion, and population concentrations.

Conceptual designs of different MRS systems were performed during this study using the DOE Hanford Site and the Nevada Test Site. On the basis of the national screening specifications used in this study, however, neither site was identified within those broad regions characterized as having a high density of favorable locations. This result illustrates the shortcomings of the nationwide screening using broadly based characteristics, since detailed knowledge of those sites show them to be highly suitable for surface storage concepts. Furthermore, both sites are being intensively studied as possible locations for the siting of geologic repositories and neither has yet been shown not to be suitable for possible repository siting. Similarly, many other areas now under intensive study within the geologic repository program would not necessarily be favored by the screening parameters used here. Final determination of the suitability of any sites will be highly dependent on local conditions and site acceptability can only be judged on such a basis.

3.5 Detailed screening

This phase was conducted in a manner similar to the national screening. However, during this phase much of the information was collected from state or regional sources. Overlay maps were prepared and combined to identify areas that met all the screening specifications.

Twenty-two states contain favorable areas for MRS tunnel facility design concepts, and 36 states contain favorable areas for surface facility design concepts. For the tunnel facility, three states were dropped from the list of states included after national screening. These were Alabama, Minnesota, and New York. For the surface facility, four states were dropped from the list. These were Mississippi, Missouri, Nebraska, and Tennessee. Most states with areas considered favorable for tunnel facilities also have areas favorable for surface storage. The areal distribution of the detailed screening results was reported by Woodward-Clyde (1981).

The mine facility search identified 18 mines or civil works located within crystalline rock with horizontal or inclined access. Of these, 4 mines are located in the favorable areas resulting from the tunnel facility detailed screening. Of those mines identified as possible sites that might be suitable for tunnel storage, two are in Montana and one each in Arizona and Wyoming.

3.6 Sensitivity analysis

In order to assess the effect of the selection of screening specifications, a sensitivity analysis was performed by varying some of the specifications for the national screening. The variations considered during the sensitivity analysis were first identified so that overlay maps could be prepared for each specification. This system allowed one to compare and contrast the land that might be acceptable by applying screening specifications that were more stringent and less stringent than the base case.

The variations that were considered during the sensitivity analysis are shown in Table 3-3. In this table, the column labeled "base case" refers to the set of screening specifications that were used in the national screening to identify areas for further consideration in the detailed screening. The columns "less stringent" and "more stringent" refer to variations on the base-case specifications that were used in the sensitivity analysis.

The results of the specific combinations of sensitivity analysis specifications that were analyzed are presented in Table 3-4. The first three lines in this table show the effects of simultaneously changing all sensitivity analysis specifications to either their less stringent or their more stringent levels. The results show that the change of included area is relatively small for tunnel facility concepts for both the less stringent and more stringent

Table 3-3. Sensitivity analysis specifications

Consideration	Measure	Sensitivity analysis specifications		
		Less stringent	Base case	More stringent
Ground-water system	Principal aquifers	Do not apply any specification and thus do not eliminate any area because of this consideration	Include areas outside principal aquifers	None
Ground motion	Location with respect to potential earthquake sources and estimated levels of ground motion	Include areas with at least a 95% probability that the peak surface acceleration in rock within a period of 130 years from known and interpreted earthquake sources will be less than 0.4g	Include areas with at least a 95% probability that the peak surface acceleration in rock within a period of 130 years from known and interpreted earthquake sources will be less than 0.2g	Include areas with at least a 95% probability that the peak surface acceleration in rock within a period of 130 years from known and interpreted earthquake sources will be less than 0.08g
Natural resources exploration and extraction	Location with respect to exploitable energy-related resources	Do not apply any specification and thus do not eliminate any area because of this consideration	Include areas outside exploitable oil, gas, anthracitic and coking coal, and geothermal areas	Include areas outside exploitable oil; oil shale; gas; anthracitic, coking, bituminous, and subbituminous coal; and geothermal areas
Population concentrations	Population density	Include areas outside counties where the population density is greater than 500 people per square mile	Include areas greater than 30 miles from counties where the population density is greater than 500 people per square mile	No more stringent specifications for this consideration
Environmental impacts	Proximity to Federal areas receiving special land-use protection	No less stringent specification for this consideration	Include areas outside national park, national wildlife refuge, and national wilderness preservation systems	Include areas outside national park, national wildlife refuge, and national wilderness preservation systems, and areas considered for inclusion in the national wilderness preservation system

Source: Woodward-Clyde Consultants, 1981.

Notes:
1. These specifications apply to both tunnel and surface concepts.
2. The sensitivity analysis specifications were applied to the national screening.
3. The designation "base case" refers to the specification that was used to identify areas to be considered in the detailed screening, as shown in Figure 3-1.

Table 3-4. Sensitivity analysis results

Sensitivity analysis case	Percentage of area of contiguous 48 states: Tunnel concepts	Percentage of area of contiguous 48 states: Surface concepts
All specifications at base-case levels	2	20
All specifications at less stringent levels	4	70
All specifications at more stringent levels	1	14
Ground-water system specification at less stringent level, others at base-case levels	--	48
Ground motion specification at less stringent level, others at base-case levels	--	22
Natural resources specification at less stringent level, others at base-case levels	--	23
Population concentrations specification at less stringent level, others at base-case levels	--	22

Source: Woodward-Clyde Consultants, 1981.

cases. Also, the change of included area is relatively small for surface concepts for the more stringent case. However, the included area increases to 70 percent of the contiguous 48 states from the base case of 20 percent for surface concepts when the less stringent specifications are used.

The last four lines of Table 3-4 identify the cause of this large change. These lines show the effects of relaxing each individual sensitivity analysis specification to its less stringent level while keeping the others at their base-case levels. The results show that the largest single change results from deleting the ground-water specification completely, which would increase the included area from 20 percent of the contiguous 48 states to 48 percent. Therefore, by deleting the ground-water specification, or using more localized knowledge about depth to the ground-water table, a substantial amount of land would be included. However, this is still substantially below the 70 percent included area that results from relaxing all specifications simultaneously. Thus, it can be concluded that a combination of factors leads to the increase of included area from 20 percent to 70 percent when the sensitivity analysis specifications are all reduced from their base-case levels to their less stringent levels. The ground-motion, population, and energy resources screening specifications each excluded approximately 22 percent. Relaxing any or all of these specifications would increase the amount of land area suitable for an MRS facility.

Finally, note that the areas shown in Table 3-4 result from performing a sensitivity analysis on the national screening specifications. Performing a sensitivity analysis at the detailed screening level would result in a further variation of the included area from what is shown in Table 3-4.

References for Chapter 3

Algermissen, S. T., and Perkins, D. M. 1976. A Probabalistic Estimate of Maximum Acceleration in Rock in the Contiguous United States. USGS Open File Report 76-416.

Hammond, R. P. 1979. "Testimony Before the Senate Committee on Energy and Natural Resources." Hearings Before the Subcommittee on Energy Regulation, Vol. 19, Publication No. 96-38, Part 2. Washington, D.C.

Jaeger, J. C., and N. G. W. Cook. 1976. Fundamentals of Rock Mechanics. John Wiley and Sons, Inc., second edition.

King, P. B., and H. M. Berkman. 1974. Geological Maps of the United States. U.S. Geological Survey.

NRC (U.S. Nuclear Regulatory Commission). 1975. Regulatory Guide 4.7, General Site Suitability for Nuclear Power Stations. Revision 1, Office of Standards Development. Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission). 1977. Safety Evaluation Report, Pebble Springs Nuclear Plants Units 1 and 2. Supplement 3, Docket Nos. 50-514, 50-515, NUREG-0013.

NRC (U.S. Nuclear Regulatory Commission). 1980a. 10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories: Licensing Procedures. Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission). 1980b. 10 CFR Part 100, Reactor Site Criteria. Washington, D.C.

NRC (U.S. Nuclear Regulatory Commission). 1981. 10 CFR Part 20, Standards for Protection Against Radiation (Proposed Rule Making). Washington, D.C.

USGS (U.S. Geological Survey). 1970. "Productive Aquifers and Withdrawal from Wells." The National Atlas of United States of America, p. 122.

USGS (U.S. Geological Survey). 1981. WATSTORE Depth to Groundwater Well Data. Computer search of data base requested by Woodward-Clyde Consultants.

Woodward-Clyde Consultants. 1981. Area/Location Screening Study for Monitored Retrievable Storage Facilities.

4 Concept Screening and Evaluation

The purpose of the screening and evaluation effort was to identify and evaluate alternative candidate concepts that could be used for a monitored retrievable storage (MRS) facility and determine if one method had superior characteristics so it could serve as a reference concept. The single reference concept would be used as the model in the evaluation of the role of monitored retrievable storage in the waste-management system.

This chapter addresses, in part, two of the questions posed in Chapter 1, namely:

1. What would an MRS system look like?
2. What concept would be selected for demonstration facilities?

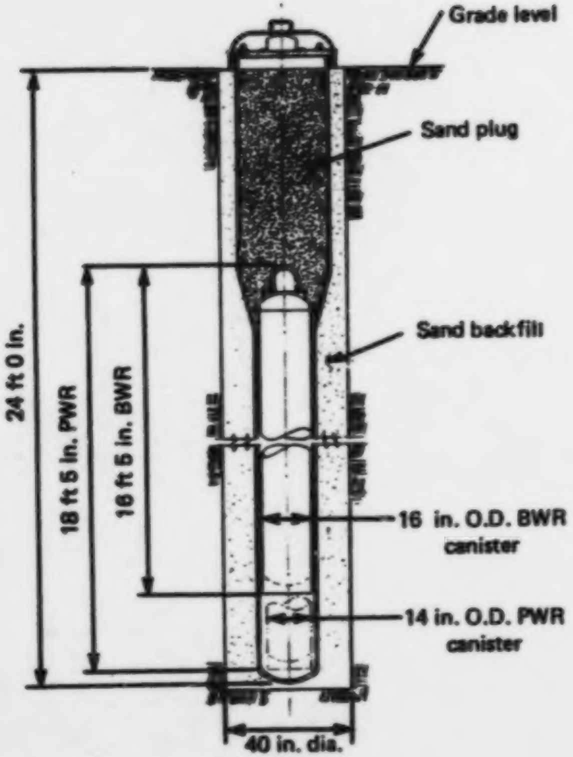
4.1 Alternative concept descriptions

Seven candidate concepts were identified for consideration as MRS facilities. The seven concepts are described in this section; the status of the technology for each concept is discussed in Chapter 5. The concepts identified are open-field dry wells, surface casks, concrete cask-in-trench, air-cooled surface vaults, closed-cycle vaults, tunnel dry wells, and tunnel rack. The characteristics of each concept are discussed below.

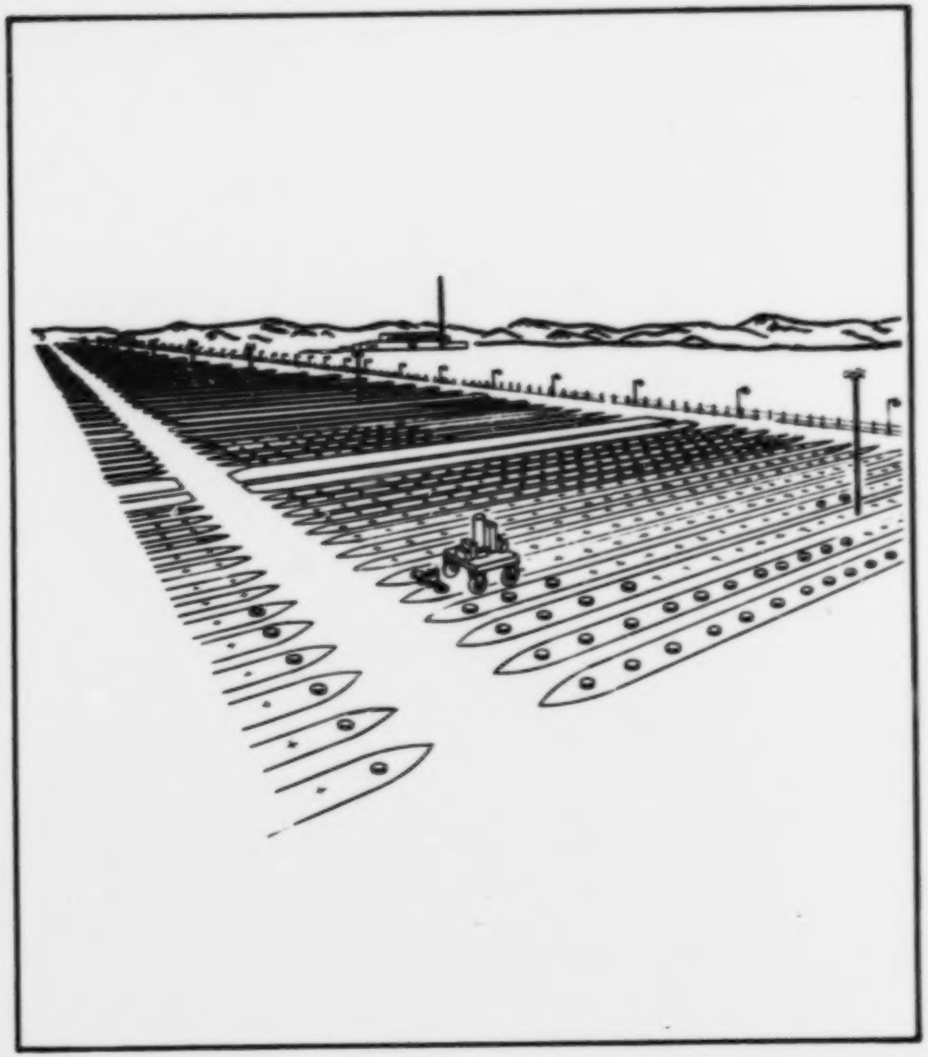
4.1.1 Open-field dry-well concept

The open-field dry-well concept (Rockwell, 1979; Westinghouse, 1981) shown in Figure 4-1 uses shallow holes (25 feet deep) drilled into the earth and lined with carbon steel and concrete to provide storage. The dry wells are arranged in a rectangular array to provide easy access for the canister transport vehicle and adequate surface area for decay heat removal. Heat transferred into the geologic media is released to the atmosphere from the surface of the field. The spacing between dry wells is determined primarily by the thermal conductivity of the earth and the thermal power output of the waste canisters. With a 17-foot spacing between dry wells the total storage area required for a full-scale facility (approximately 48,000 MTHM of spent fuel) would be approximately 1000 acres.

The open-field dry-well concept provides a dual level of containment. First, the spent fuel or solidified high-level waste is hermetically sealed in a high-integrity canister. The canister is then placed in the steel liner in the ground which in turn is welded closed to provide the second containment barrier. Radiation shielding is provided by the earth and a plug that is placed over the top of the canister.


Grade level
Sand plug
Sand backfill
24 ft 0 in.
18 ft 5 in. PWR
16 ft 5 in. BWR
16 in. O.D. BWR canister
14 in. O.D. PWR canister
40 in. dia.

Typical dry well



Monitoring is accomplished by the periodic checking and recording of the canister/liner interspace pressure and the liner wall temperature. Samples of annulus air can be withdrawn and analyzed for evidence of package stabilizer gas or krypton-85 leakage from the package canister.

Transportation of the canisters from the receiving and packaging facility to the field dry wells is accomplished by rubber-tired shielded transport vehicles. Similar vehicles are provided for shield plug placement, liner closure, and pressurization.

4.1.2 Surface cask concept

The surface cask concept (Morgan, 1977; Atlantic Richfield, 1976) shown in Figure 4-2 uses hollow reinforced-concrete cylinders approximately 10 feet in diameter and 20 feet high and weighing over 100 tons to provide storage. The casks are arranged in a rectangular array in an open field on approximately 15-foot centers.

The cask concept provides a single level of containment with the hermetically sealed canister that contains the spent fuel or solidified high-level waste. Each cask can hold four canisters of waste. The canisters must be loaded into the cask in a shielded facility and the cask plugged to provide protection from radiation. The loaded cask must be transported to the storage location in the open field. A full-scale facility (approximately 48,000 MTHM of spent fuel) would require about 25,000 casks and a minimum of 650 acres of storage area; a facility for high-level waste could require as few as 4500 casks. Radiation protection is provided by the concrete cylinder.

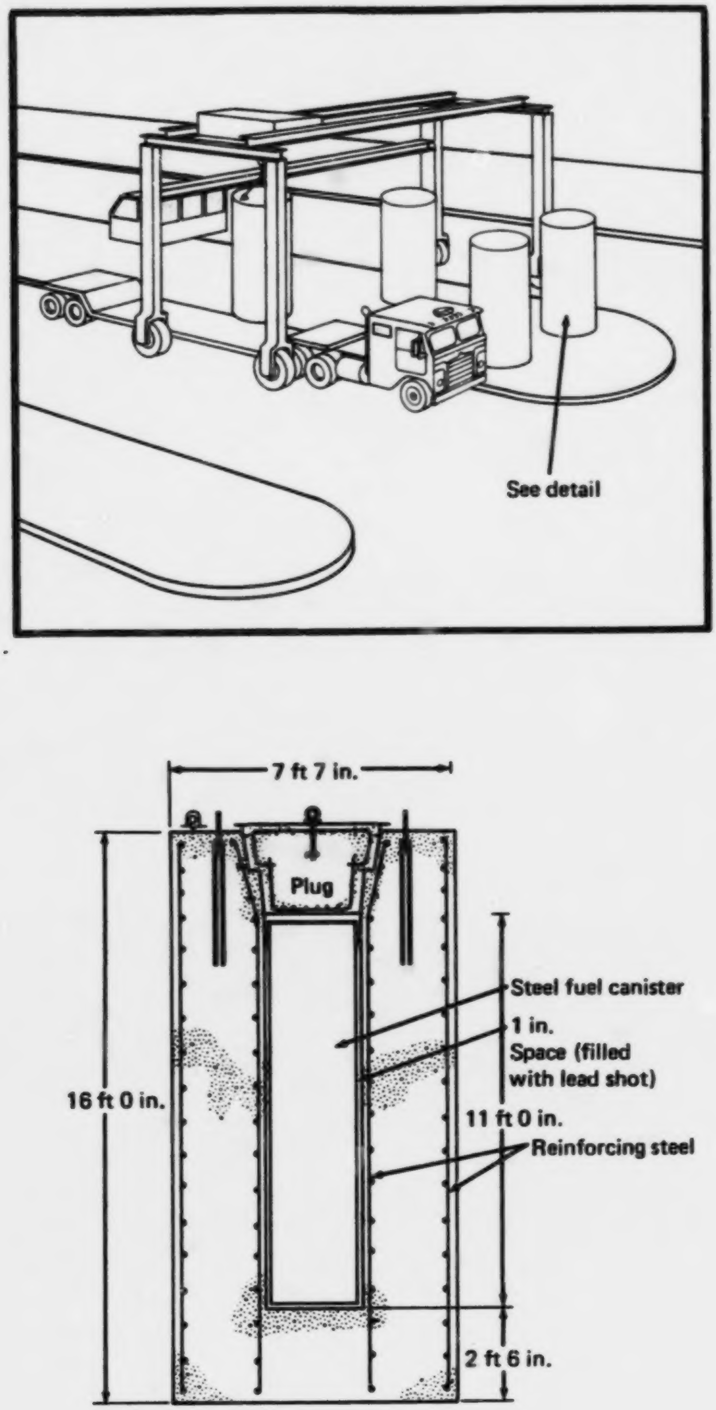
The heat from the radioactive decay is removed by conduction through the concrete cylinder. The cask walls are in turn cooled by natural convection to the atmosphere.

Monitoring is accomplished by periodic checking of the cask temperatures by thermocouples and conventional air sampling instruments within the casks and around the field of casks. In addition, the interspace between the canister and racks can be sampled for tracer or radioactive gases.

4.1.3 Concrete cask-in-trench concept

The concrete cask-in-trench concept (Rockwell, 1978) shown in Figure 4-3 is a variation of the surface cask concept. The reasons for burying the cask are for (1) greater protection against major external events such as earthquakes and tornadoes and (2) reduced visual impact compared to the above-surface concept.

All systems and operations are the same as for the surface cask concept, except for the placement of the cask. The storage cask is delivered to the storage location in the same manner except it is placed in an excavated trench. The trench is subsequently


See detail
7 ft 7 in.
Plug
Steel fuel canister
1 in.
Space (filled
with lead shot)
16 ft 0 in.
11 ft 0 in.
Reinforcing steel
2 ft 6 in.

Detail

Figure 4-2. Surface cask concept.

BEST DOCUMENT AVAILABLE

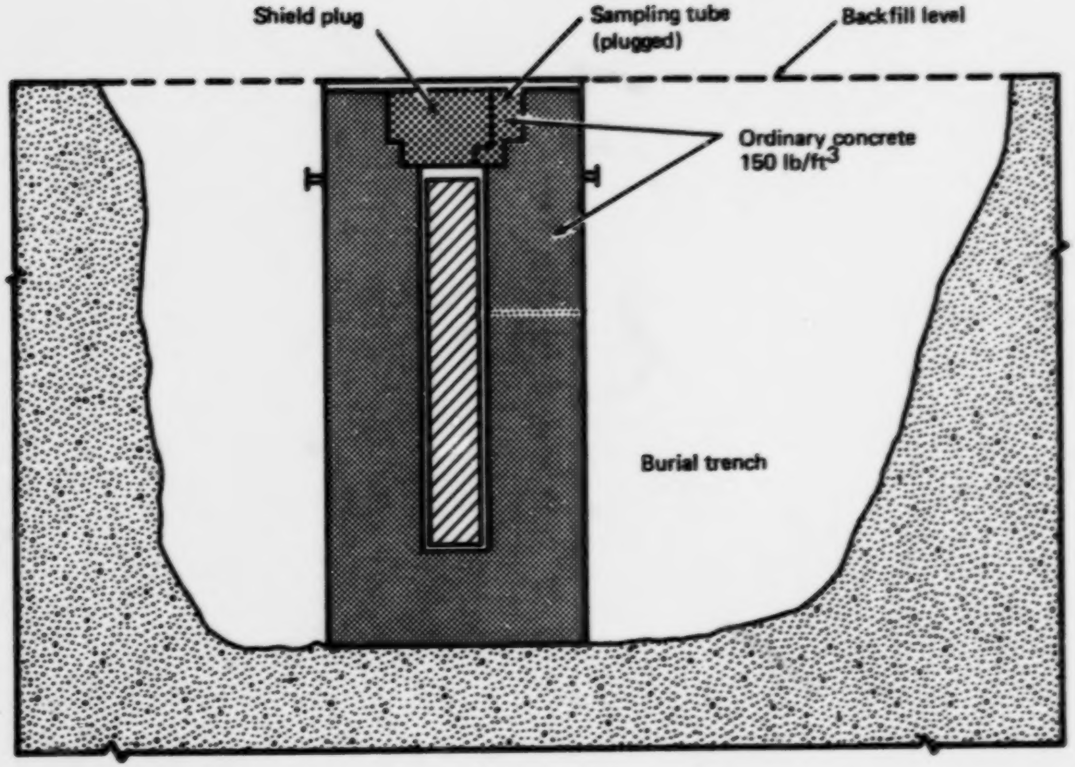

Shield plug
Sampling tube (plugged)
Backfill level
Ordinary concrete 150 lb/ft^3
Burial trench

Figure 4-3. Concrete cask-in-trench concept.

filled until the earth is flush with the top of the cask to provide access for surveillance. Approximately the same spacing and area requirements are assumed for this concept; however, detailed thermal analysis to confirm this assumption has not been completed.

4.1.4 Air-cooled surface vault concept

The air-cooled surface vault (Atlantic Richfield, 1974, 1976) shown in Figure 4-4 consists of a reinforced concrete building for the storage of encapsulated spent fuel or solidified high-level waste. Canisters are stored in holes in the floor of the building in a tightly packed array. Heat from the radioactive decay is removed by air circulating around the canisters. The air circulation is driven by the natural draft caused by the heated air. A full-scale facility would require approximately 20 acres.

This concept provides only a single level of containment with the hermetically sealed canister that contains the spent fuel or solidified high-level waste. Radiation protection is provided by the concrete in the structure.

Monitoring of the canisters is accomplished by placing continuous monitors in the exit air stack to detect radioactivity and throughout the area within the vaults. In addition, temperature measurements within the vault monitor the heat-removal performance of the system.

4.1.5 Closed-cycle-cooled vault concept

The closed-cycle-cooled vault concept (Electrowatt, 1980) shown in Figure 4-5 uses massive concrete blocks with multiple, steel-lined holes to provide storage. Spent fuel or solidified high-level waste is encapsulated in a hermetically sealed canister with special fins that provide efficient cooling in a confined closed system. Heat from radioactive decay is removed from the waste canister by an internal closed-cycle convection cooling approach and transferred to the monolith by radiation and natural convection. The walls are cooled by heat pipes that transfer the heat to the outside of the structure where it is dissipated in the atmosphere by ambient air circulation. A full-scale facility would require approximately 25 acres of land.

The closed-cycle vault provides a dual level of containment. First, the spent fuel or solidified high-level waste is hermetically sealed in the special canister. The canister is then placed in the steel liner in the concrete monolith which in turn is sealed mechanically. Radiation protection is provided by the concrete of the structure.

Each storage location is individually monitored for temperature. Monitoring for radionuclide leakage outside the canister consists

BEST DOCUMENT AVAILABLE

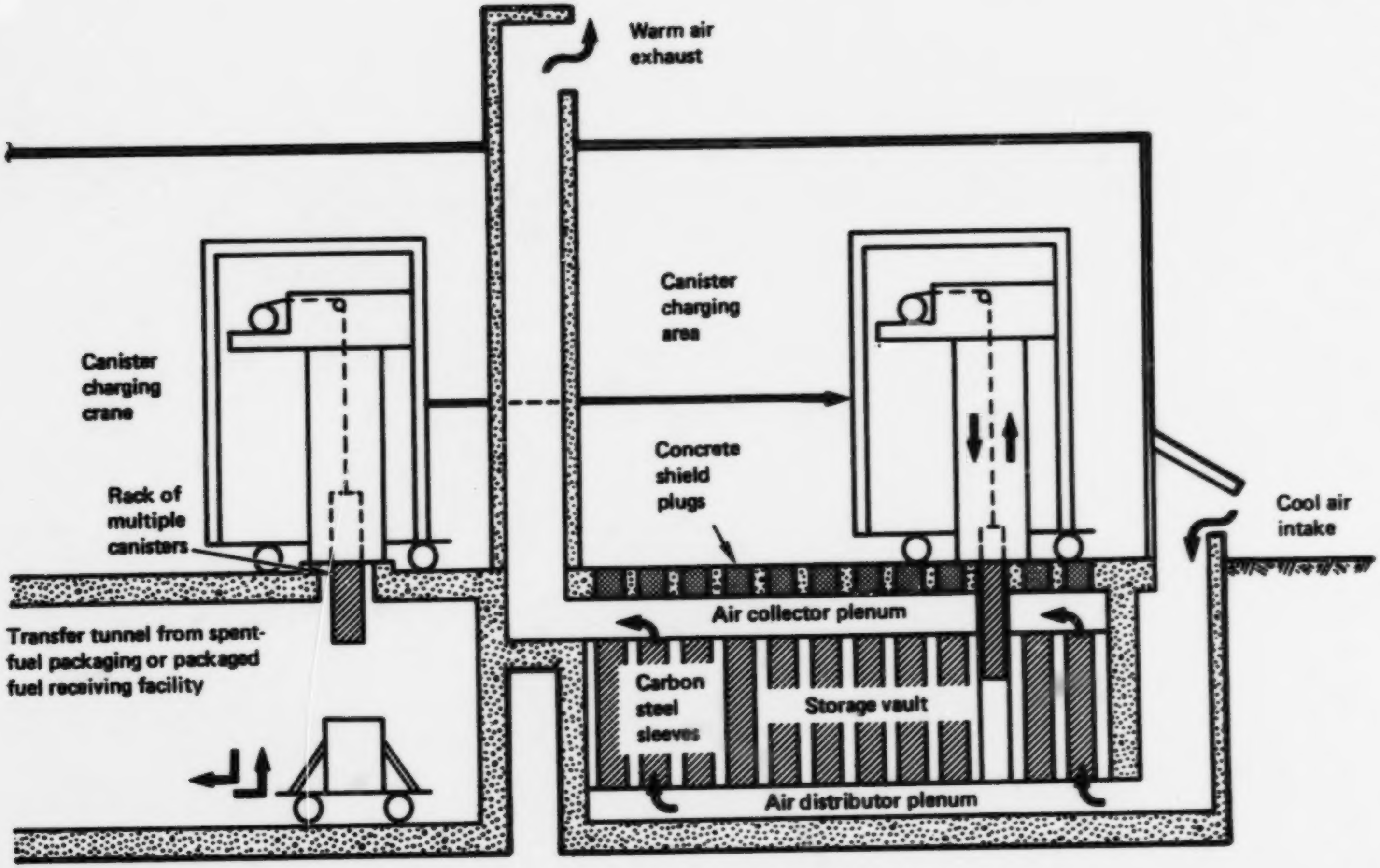
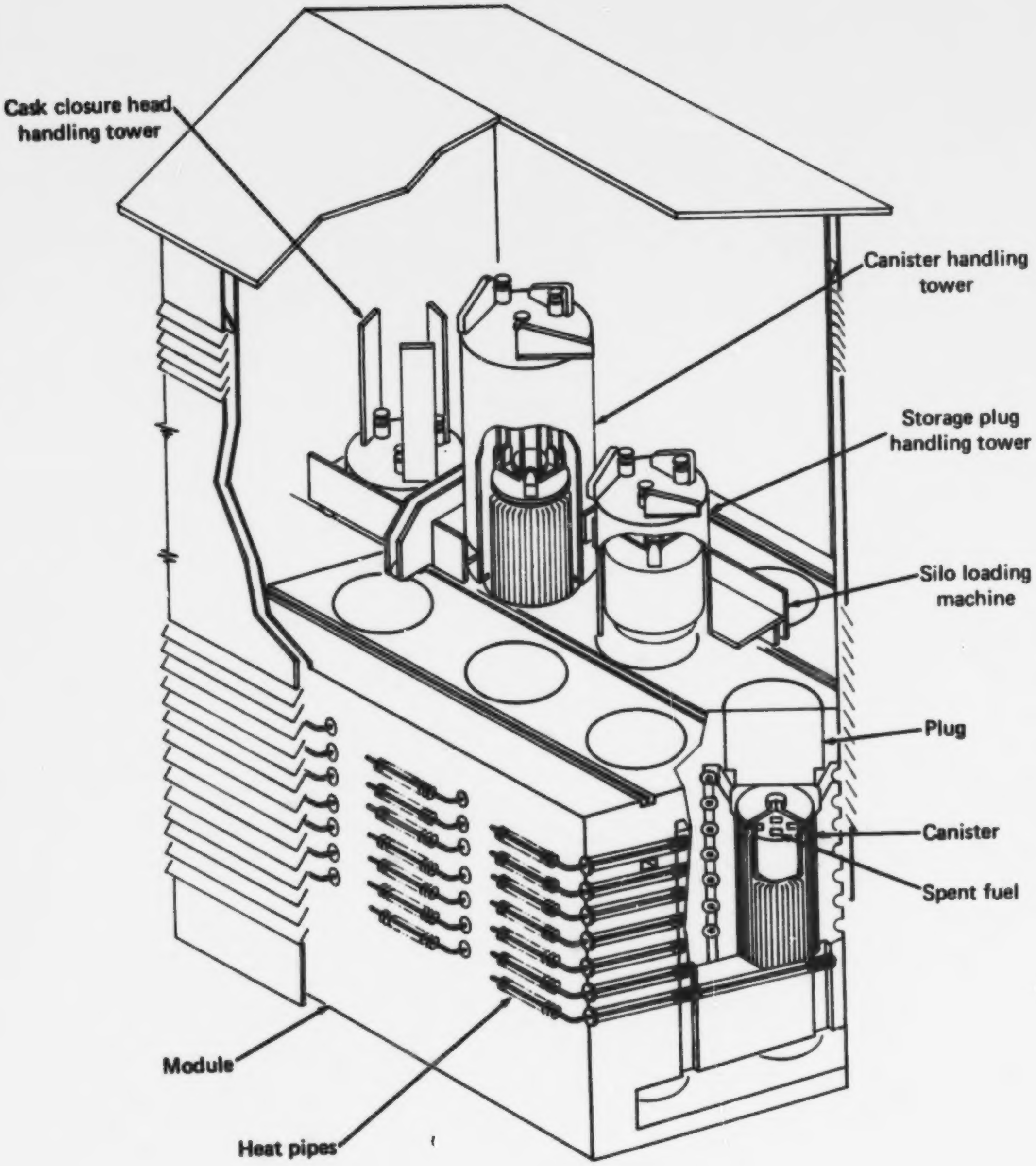

Warm air exhaust
Canister charging area
Canister charging crane
Concrete shield plugs
Cool air intake
Rack of multiple canisters
Air collector plenum
Transfer tunnel from spent-fuel packaging or packaged fuel receiving facility
Carbon steel sleeves
Storage vault
Air distributor plenum

Figure 4-4. Air-cooled surface vault concept.

BEST DOCUMENT AVAILABLE


Cask closure head handling tower
Canister handling tower
Storage plug handling tower
Silo loading machine
Plug
Canister
Spent fuel
Module
Heat pipes

Silo loading

Figure 4-5. Closed-cycle vault concept.

of periodic sampling of each storage location for measurable amounts of tracer or radioactive gas.

4.1.6 Tunnel dry-well concept

The tunnel dry-well concept (Westinghouse, 1981) shown in Figure 4-6 uses a hole about 25 feet deep in the floor of a mined structure in the side of a mountain to provide storage for canisters of spent fuel or solidified high-level waste. The dry wells are arranged in a liner array in the tunnels. The tunnels, approximately 500 feet long, contain two rows of dry wells on 12-foot centers. This configuration provides easy access for the canister transport vehicle. The heat transferred to the geologic media is dissipated by conduction into the massive rock formation. No forced cooling is required for safe storage of the material; however, a powered ventilation system for temperature control is required for personnel access to the facility for surveillance and monitoring. Because of the requirement to have pillars between the rooms, the area required for a full-scale tunnel dry-well storage facility with a capacity of 48,000 MTHM of spent fuel is 2300 acres. Another 2000 acres would be required for the spoilage piles from mining and for the packaging and other administrative facilities.

The tunnel dry-well concept provides a dual level of containment. The spent fuel or solidified high-level waste is hermetically sealed in a high-integrity canister. The canister is then placed in the steel liner in the ground which in turn is sealed by welding, which provides the second containment barrier. Radiation protection is provided by the rock and a plug that is placed over the top of the canister.

Monitoring is accomplished by the periodic checking and recording of the canister/liner interspace pressure and the liner wall temperature. Samples of annulus air are also withdrawn and analyzed for evidence of package stabilizer gas or krypton-85 leakage from the package canister.

Transportation of the canisters from the receiving and packaging facility to the dry wells is accomplished by rubber-tired shielded transport vehicles. Similar vehicles are provided for shield plug placement, liner closure, and pressurization.

4.1.7 Tunnel-rack concept

The tunnel-rack concept (General Atomic, 1981a) shown in Figure 4-7 consists of a mined underground structure with horizontal access for the storage of encapsulated spent fuel or solidified high-level waste. Fifty canisters of waste are tightly grouped in a rack. The rack is moved down a central tunnel and placed in an enclosed, prestressed concrete module that extends the entire length of the 550-foot storage drift. The rack of canisters is moved entirely by remote-handling equipment that consists of a canister conveyor, a rack transporter, and a control power car. Each 550-foot-long

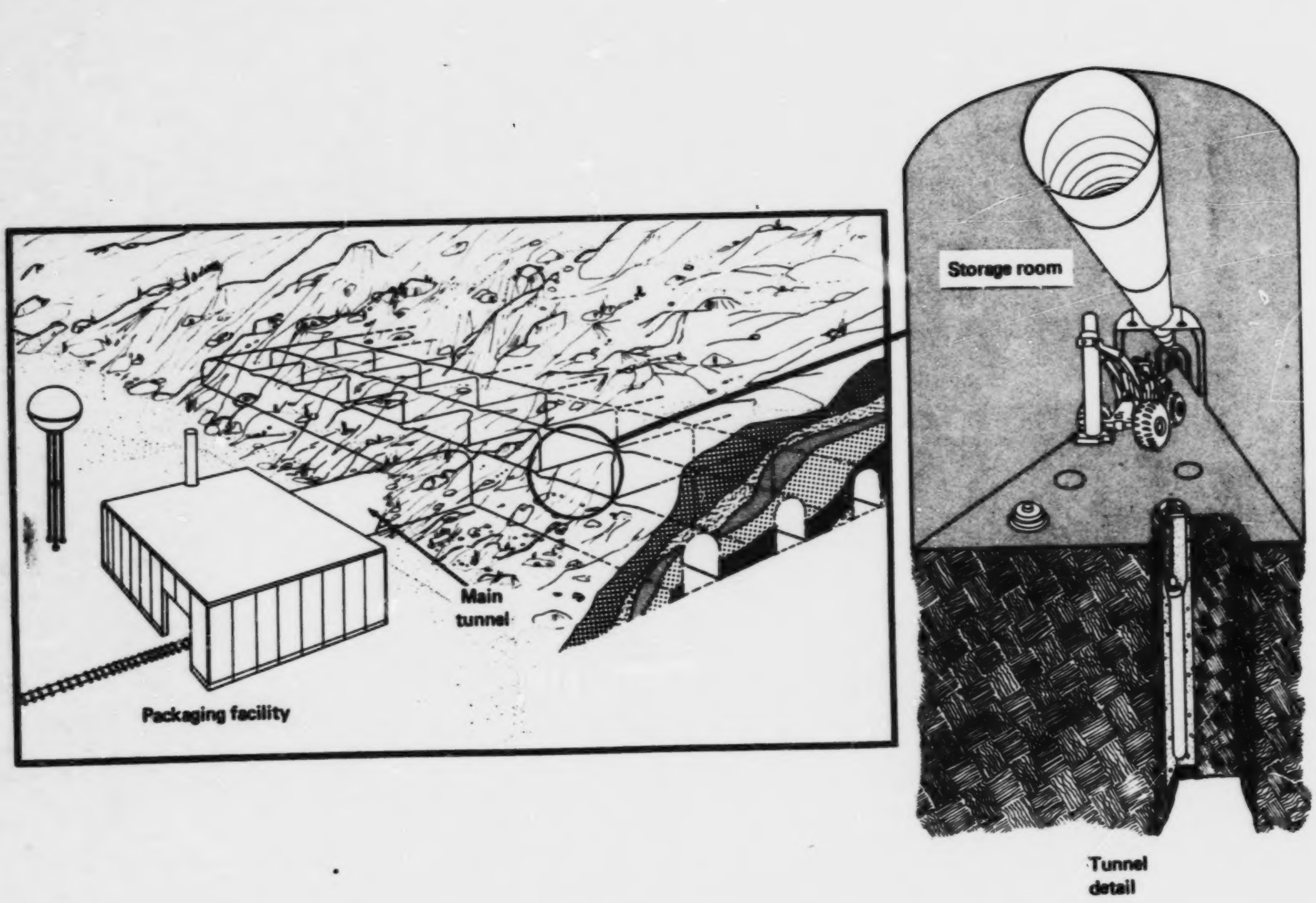

Storage room
Main tunnel
Packaging facility
Tunnel detail

Figure 4-6. Tunnel dry-well concept.

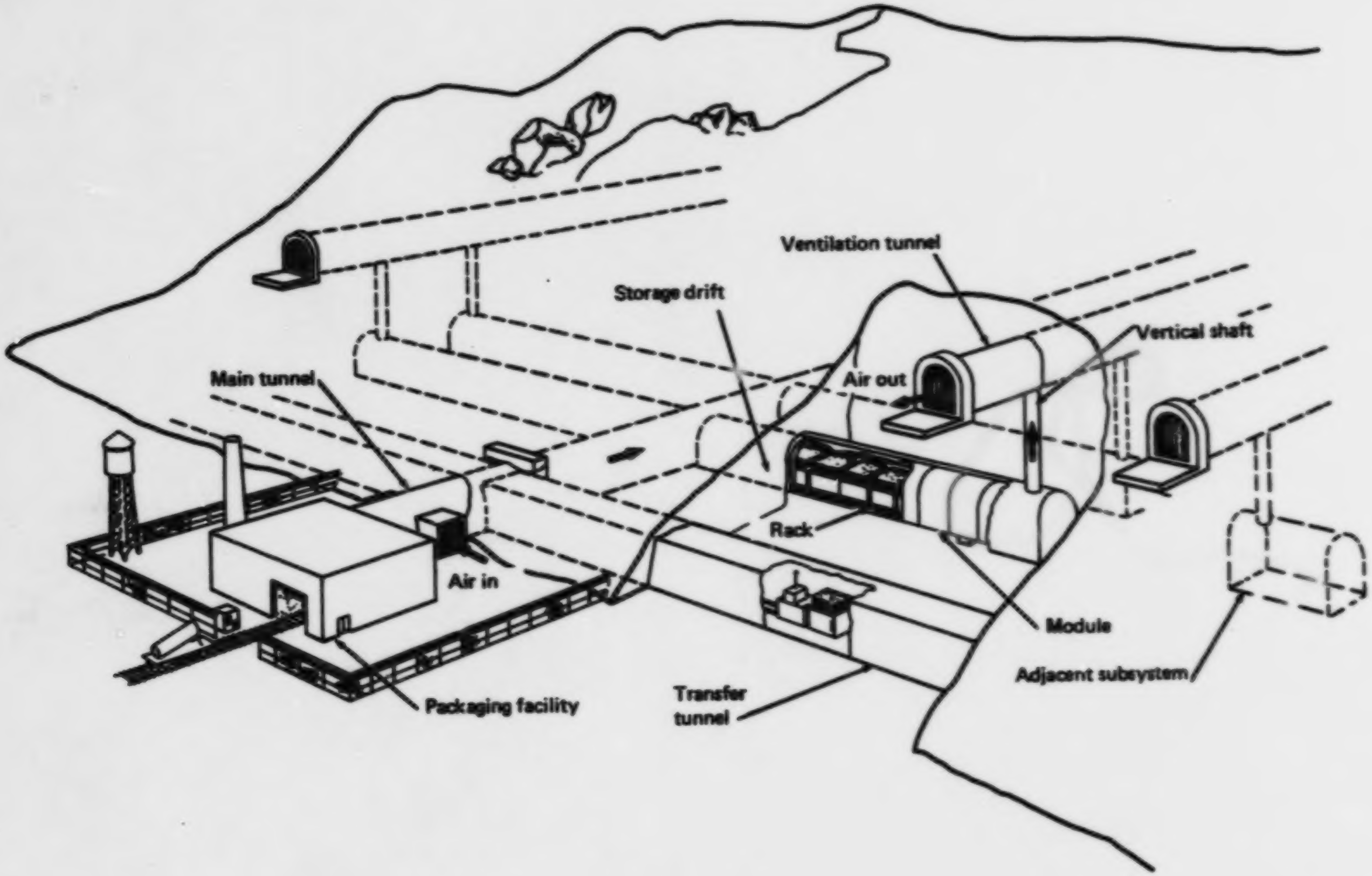

Ventilation tunnel
Storage drift
Vertical shaft
Air out
Main tunnel
Rack
Air in
Module
Adjacent subsystem
Packaging facility
Transfer tunnel

Figure 4-7. Tunnel-rack concept.

storage module, which is insulated to protect the concrete from the high temperatures, provides storage for 40 racks of canisters. Approximately 175 acres of subsurface storage would be required for a full-scale facility.

This concept provides a single level of containment with the hermetically sealed canister. No radiation protection is provided in the storage area; all operations must be done remotely.

Monitoring in the tunnel-rack concept is provided by remote television viewing of the stored canisters. Each canister is provided with a pressure indicating device that monitors internal pressure. When pressure is lost in the canister, a visual indicator is actuated. The television system observes the indicator and the rack with the canister is removed from the tunnel to permit overpacking of the leaking canister. In addition, continuous radiation air monitors are provided in the vertical vent stack of each drift to detect any release of radioactive material.

4.2 Evaluation of alternative concepts

4.2.1 Evaluation factors

Each of the seven concepts identified for detailed review were evaluated (General Atomic, 1981b) using the following factors: (1) health and safety of operating personnel and the general public, (2) licensing and regulatory concerns, (3) monitorability and retrievability, (4) reliability, availability, and maintainability, (5) implementation schedule, (6) site adaptability, (7) environmental impact, (8) system interaction and flexibility, (9) socioeconomic impact, and (10) design and development cost.

4.2.2 Evaluation process

A rigorous comparison of each of the concepts is not currently possible since the amount of design information available on each varies so widely. Consequently a form of modified Delphi approach was used to evaluate the alternative concepts. A panel of 10 technical and economic specialists defined evaluation criteria for each of the factors noted above and undertook the evaluation. The disciplines incorporated in the panel were Licensing, Safety and Reliability, Cost Development, Systems Engineering, and Project Management.

Each of the evaluation criteria were weighted according to perceived importance by having the panel independently rate each evaluation criterion on a scale of 1 to 10. Based on these individual rankings, a consensus (General Atomic, 1981b) regarding weight and rank was established. Numerical values were assigned for each evaluation criterion using a subjective evaluation based on the engineering judgment of the specialist. The numerical values were arithmetically summed to obtain a relative merit value. These were then combined on a criteria-weighted basis to provide a total figure of merit for each concept. This factor was taken as an indicator of the relative ability of the concept to satisfy the requirements for an MRS facility.

4.3 Results

The evaluation resulted in a close grouping of the total figure-of-merit for each concept. The numerical values were all within 10 percent of a mean value. It appears that the presently available definition of each of these concepts does not permit a clear-cut selection of a concept as best suited for monitored retrievable storage.

Since there was not a clear cut basis for selecting a single concept for the demonstration facilities and for the analysis of the impact on the waste-management system, three concepts were picked for further study. They were the dry wells in open field, dry wells in tunnels, and the tunnel-rack concepts. The dry-well concept, both in open fields and tunnels, is a technique that has the greatest background of experimental work and use. The tunnel-rack concept was investigated since it is a technique that has received significant attention in the past 2 years and the one for which the least study had been conducted.

References for Chapter 4

Atlantic Richfield Hanford Company, Kaiser Engineers. 1974. Retrievable Surface Storage Facility Alternative Concept Engineering Studies. ARH-2888 Rev., Richland, Wash.

Atlantic Richfield Hanford Company, Kaiser Engineers. 1976. Retrievable Surface Storage Facility Conceptual System Design Description. ARH-LD-140, Richland, Wash.

DOE (U.S. Department of Energy). 1979. Technology for Commercial Radioactive Waste Management, Volume 3. DOE/ET-0028, Washington, D.C.

Electrowatt Eng. Soc. Limited. 1980. Dry Spent Fuel Storage, Imatran Voima Osakeyhtio Lavisa, Nuclear Power Plant Feasibility Study. Geneva.

General Atomic Company. 1981a. Monitored Retrievable Storage Concept Definition and Evaluation. GA-A16424, San Diego, Calif.

General Atomic Company. 1981b. Monitored Retrievable Storage Tunnel Rack Concept Preconceptual Design Report. GA-A16370, San Diego, Calif.

Morgan, W. W. (ed.). 1977. "Report by the Committee Assessing Fuel Storage, Part 2: Appendices." Atomic Energy of Canada Limited Report. AECL-5959/2.

Rockwell Hanford Operations. 1978. Engineering Study of Dry Near-Surface Interim Storage of Fast Flux Facility Spent Fuel. RHO-LD-66, Richland, Wash.

Rockwell Hanford Operations. 1979. Dry Well Storage Facility Conceptual Design Study. Report No. 79-8-R, Richland, Wash.

Westinghouse Electric Corporation. 1981. Conceptual Design Evaluation Study for Interim Off-Site Spent Fuel Storage Installation. WI 81-176, Pittsburgh, Pa.

5 Technology

5.1 Introduction

The feasibility of introducing the monitored retrievable storage (MRS) concept into the waste-management system depends on the availability of the technology necessary to satisfy the technical requirements of an MRS system. As a part of this study, an evaluation of the technology required to design and construct an MRS system was conducted, and an assessment of the adequacy of currently available technology was made. This chapter addresses in part a question posed in Chapter 1, namely: How long would it take to implement an MRS system?

Six broad functional requirements for all MRS concepts were established, and the technological requirements for each were identified. Where it was determined that technological deficiencies or uncertainties existed, they were identified. If any of the seven concepts described in Chapter 4 were to be implemented as an MRS facility, the current technical inadequacies would have to be addressed.

5.2 Requirements for an MRS facility

5.2.1 Functional requirements

The following functions were specified as requirements for any MRS facility:

1. Provide storage of spent fuel and high-level waste for a minimum of 100 years.
2. Provide protection from extreme environmental events and accidental or deliberate intrusion.
3. Provide shielding and containment of radioactive material to protect the environment and the health and safety of the public and operating personnel.
4. Provide decay heat removal systems using passive cooling methods.
5. Provide retrieval capability throughout the entire storage period.
6. Provide warning of potential and actual release of radioactive material.

5.2.2 Technical requirements

Technical capability must be available for design, construction, operation, and decommissioning. The level of development of the different MRS concepts in meeting these requirements has been evaluated. The results of the evaluation of the receiving and packaging, storage, and retrieval operations are presented below.

5.3 Review of technological status of MRS concepts

An evaluation of the status of the technology necessary to implement the various MRS concepts was performed. Much of the technology necessary for storage of spent fuel and high-level waste has been developed, or is being developed and actively tested today. The review revealed a number of areas where additional research and development would be required before any commitment to construct a facility.

A major uncertainty exists concerning the information that would be required to obtain a license for such a facility. Although Title 10, Part 72, of the Code of Federal Regulations has been issued, the Nuclear Regulatory Commission (NRC) has not yet licensed a facility under this regulation. Therefore, any conclusion regarding the need for additional research and development must be tentative pending additional information regarding NRC licensing requirements.

5.3.1 Receiving and packaging

It was noted earlier that the MRS concept depends on a hermetically sealed canister to provide containment of the radionuclides. This fact establishes a requirement for technology to receive and encapsulate spent-fuel elements or processed high-level waste. Facilities for receiving and packaging normally include the following functional capabilities: (1) transportation cask interface and cask loading and unloading, (2) spent-fuel and high-level waste handling and packaging, (3) package inspection and testing, and (4) preparation for emplacement. Such facilities can be designed, built, operated, and decommissioned with available technology.

5.3.2 Storage and retrieval

For the purpose of discussion, the seven MRS concepts considered in the study have been grouped into three general storage methods as follows:

Storage method	MRS concept
Dry wells	Open-field dry well Tunnel dry wells
Casks	Surface cask Cask-in-trench
Vaults	Air-cooled surface vault Closed-cycle-cooled vault Tunnel rack

5.3.2.1 Technology status of dry wells

The technology needed to design and construct dry wells (both surface and tunnel) is well established. Experiments to evaluate the thermal characteristics of soil and rock using heaters have been conducted and substantial experience (Westinghouse, 1980a,b) has been gained with temporary storage of spent fuel as noted in Figure 5-1. The dry well in tunnel is identical in concept to the current emplacement approach for a deep geologic repository. Substantial work is under way to evaluate thermal and structural design requirements for the emplacement of waste in a geologic repository, and these requirements will be directly applicable to tunnel dry-well storage.

With the exception of the long-term behavior of some geologic media and construction materials at elevated temperatures, no significant research and development can be identified for dry-well storage. Before a final statement can be made concerning research and development for open-field dry wells, the methods to conduct a safety analysis for such a facility will have to be reviewed.

5.3.2.2 Technology status of casks

The surface concrete-cask storage concept has been studied experimentally since 1975 (Westinghouse, 1980a,c). The experimental work to date is presented in Figure 5-1. Design codes for concrete structures in nuclear service are well established and available. Analytical codes for radiation shielding and heat dissipation by concrete are well tested. There is no practical experience with the cask-in-trench concept, and additional work will have to be done to resolve uncertainties about the thermal analysis of this configuration.

With regard to the safety analysis of an MRS facility based on storage casks, a thorough review of such methods will have to be made. Additional research and development may be required to establish a way to evaluate the risk of a cask storage facility.

5.3.2.3 Technology status of vaults

Air-cooled surface vaults are currently in use for storing spent fuel at the Idaho National Engineering Laboratory (Westinghouse, 1980a) and in England (Dixon, 1981). The operational experience with air-cooled vaults is shown in Figure 5-1. The radioactive decay heat is removed by a ventilation system that includes forced air or naturally circulating air. With the exception of those design features associated with natural convection cooling, all technology required to build and operate such a facility is currently available.

Closed-cycle-cooled vaults would provide for an additional level of containment beyond the direct-air-cooled vault. With this concept, large specially cooled waste packages within a hermetically sealed vault transfer the heat through a system of "heat pipes"

	STORAGE LOCATION	AVAILABLE STORAGE SPACES	FUEL TYPE/CONTENTS	HEAT GENERATION PER UNIT
AIR COOLED VAULT	• NEVADA–NTS–EMAD	24	PWR	2.0 KW
	• UNITED KINGDOM–WALES	28,800	AGR–MAGNOX	0.06 KW
	• IDAHO–INEL	636	HTGR–FSV	TBD
			HTGR–PBI CORE 2	0.5 KW
			HTGR–ROVER	0.0 KW
DRYWELLS			ELECTRIC	1-5 KW
	• WASHINGTON–HANFORD (Basalt)	2	GLASS	
	• WASHINGTON–HANFORD (Soil)	1	ELECTRIC	1.0 KW
	• NEVADA–NTS–CLIMAX (Granite)	17	PWR	2.4 KW
	• NEVADA–NTS–EMAD (Soil)	4	PWR	0.9 KW
	• NEVADA–NTS–EMAD (Soil)	11	ELECTRIC	1, 2, & 3 KW
	• IDAHO–INEL (Soil)	61	LMFBR – FERMI I	.7 KW (0)
			HTGR – PBI, CORE 1	.8 KW (0)
			LMFBR–EBR–II	0.0 KW
	• IDAHO–INEL (Soil)	861	MISC. RADIOACTIVE SCRAP	0.0 KW
	• KANSAS–PSV (Salt)	15	ETR FUEL & ELEC. HEATER	1.5 KW
			ELECTRIC	1.5 KW
SURFACE STORAGE CASK	• GERMANY – WÜRGASSEN	(8 Casks)	BWR	N/A
	• NEVADA–NTS–EMAD	2	PWR	0.9 KW
	• WASHINGTON–HANFORD	1	ELECTRIC	5.0 KW, 10.0 KW
	• CANADA–WHITESHELL	7	WR-1	2.0 KW
			WR-1	2.0 KW
			HPWR–CANDU	2.0 KW
			ELECTRIC	2.0 KW, 11.0 KW
			WR-1	2.0 KW
			ELECTRIC	2.0 KW, 5.0 KW

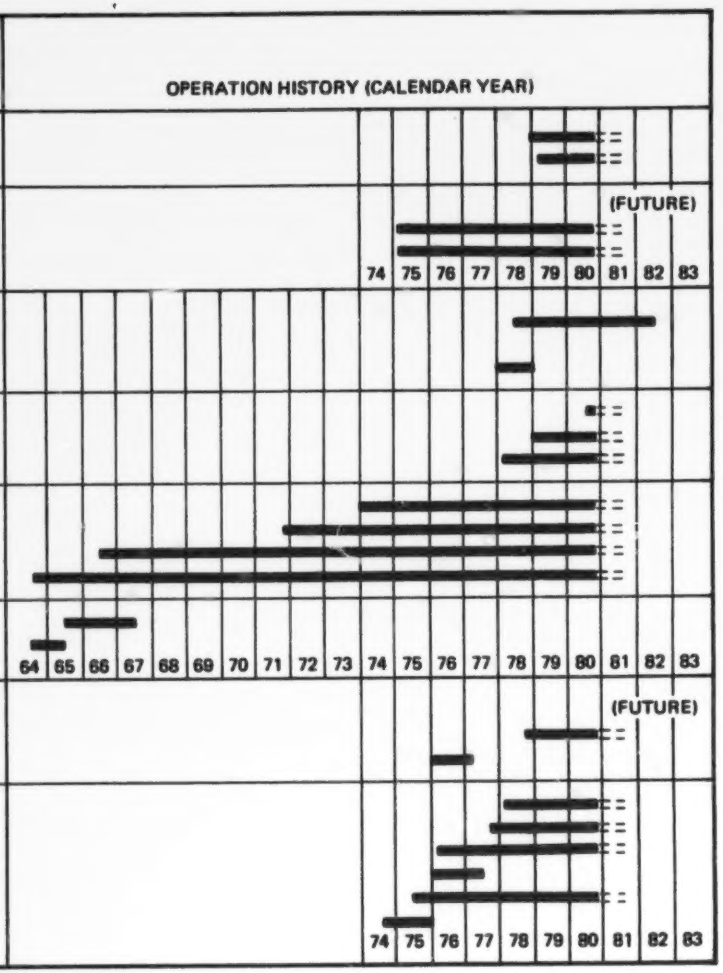


Figure 5-1. Summary of experimental test of MRS concepts.

BEST DOCUMENT AVAILABLE

which are in turn cooled on the outside of the vault. There is currently no experience with such a system. One conceptual design has been developed, and extensive analysis will have to be undertaken if this concept is to be pursued.

The tunnel-rack concept has not been experimentally tested. The first conceptual design of such a facility was completed in July 1981 (General Atomic, 1981) as specific input for this report. The technology for building and stabilizing the large diameter tunnels required for this approach has been demonstrated, although there will be some constraints on the quality of rock in which the tunnels will be built. The tunnel-rack concept as presented in the conceptual design will use prestressed concrete structures, natural convection cooling, and total remote-handling and remote-sensing operations. The operation of the facility in terms of emplacement and retrieval of material is dependent on a totally remote system that has fairly close tolerances.

Before a commitment could be made to base a major facility on the tunnel-rack concept, a significant research and development program would have to be conducted covering such areas as reliability of the remote-handling operations, the effectiveness of natural circulation in cooling closely packed waste packages, the effect of high temperature on the concrete and rack in the ventilation shafts and tunnels, and the impact of radiation and high weight loads on the prestressed concrete box bridge designs. In addition, investigation will have to be done to determine the impact that structural misalignments might have on the operations of the remote-handling systems for emplacement and retrieval, and to what degree natural geologic and man-initiated events might contribute to misalignment.

References for Chapter 5

Dixon, D. 1981. "The Long-Term Dry Storage of Irradiated Oxide Fuel and Vitrified Waste." Nuclear Engineering International, Vol. 26, Issue 316, pp. 32-36.

General Atomic Company. 1981. Monitored Retrievable Storage Tunnel Rack Preconceptual Design. GA-A16370, San Diego, Calif.

Westinghouse Electric Corporation. 1980a. Dry Storage Technology Development Program Survey of Existing Experience. WI 80-261, Pittsburgh, Penn.

Westinghouse Electric Corporation. 1980b. Electrically Heated Dry-Well Storage Test (1 kW and 2 kW Operation). AESD-TME-3037, Pittsburgh, Penn.

Westinghouse Electric Corporation. 1980c. Thermal Evaluation of Sealed Storage Cask Containing Spent Fuel. AESD-TME-3050, Pittsburgh, Penn.

6 Demonstration Facility Description

6.1 Background

This chapter presents the results of studies for the site-specific conceptual designs for the monitored retrievable storage (MRS) demonstration facility. Three specific items of information were to be derived from these conceptual design studies: (1) a visual representation of what the facility might look like, (2) how much it might cost, and (3) how long it would take to design, license, and build.

The selection of specific sites for conceptual designs of an MRS demonstration facility was viewed by state officials as a possible expression of intent to proceed with the construction of a facility by the U.S. Department of Energy (DOE). Therefore, in order to allow design studies to begin without delay, a decision was made to use sites already in the control of the Department of Energy.

The sites selected for use in the conceptual design studies have been extensively characterized so that a substantial site-specific data base is available. Construction work, including tunneling similar to what might be required to build an MRS demonstration facility, has been accomplished at both sites. Consequently, there are cost and productivity data available for use in preparing reasonable cost and schedule estimates.

The sites used as a basis for these conceptual designs were the Hanford Site and the Nevada Test Site. Before these two sites were selected, a number of other DOE-controlled sites were assessed for their suitability to such a study.

The following basic guidelines were used in carrying out the conceptual design studies:

1. In the facility design, the package must provide the containment of radionuclides while the facility is to provide protection of the package against natural and man-made events.
2. The facility and package must allow the complete retrieval of all processed waste and/or spent fuel for a period of 100 years.
3. The health and safety of the public and the staff must be protected over the life of the facility.
4. The facility would be licensed by the U.S. Nuclear Regulatory Commission.
5. A demonstration facility would be able to accommodate 1000 packages of spent fuel and up to 1000 packages of

processed high-level waste. This capacity should be capable of being filled at a rate of 1000 canisters per year.

6. The demonstration facility should be capable of being expanded to a full-scale facility handling one-third of the spent fuel or high-level waste generated by approximately 150 gigawatts electric-generating capacity.

The conceptual designs developed for the Hanford Site and the Nevada Test Site are different in several important details that significantly affect the cost estimates of the facility. The major differences are the following:

1. The receiving and packaging facility design for the Hanford Site uses "wet" unloading, storage, and handling; the Nevada Test Site design uses an entirely "dry" process.
2. The design of the canisters and dry-well encasements for the Hanford Site are based on more conservative criteria and assumptions than those used for corresponding components at the Nevada Test Site.
3. The design of the monitoring systems vary considerably. The Hanford Site design employs a system built into the storage units that allows for rapid monitoring; the Nevada Test Site design uses a selective monitoring-by-inspection approach.
4. Sites must be located such that adverse geologic and hydrologic conditions are avoided.

Sections 6.2 and 6.3 describe the conceptual designs for possible facilities at the Hanford Site and the Nevada Test Site, respectively.

6.2 Conceptual designs for the Hanford Site

Two conceptual designs for storage have been developed (Rockwell, 1981) for the Hanford Site: (1) dry well in open fields and (2) tunnel rack.

6.2.1 Siting

The site requirements for these two concepts are quite different since the dry well would be located at the surface and the tunnel would be located within a mountain. However, the following general requirements are common to both concepts:

1. Facilities must be located on the Hanford Site.
2. Facilities must be located so as not to interfere with the operations of existing facilities.

3. Facilities must be located as near as possible to the existing waste-management activities (200 East and 200 West areas).

In addition to these general requirements, the following requirements are specific to the open-field dry-well concept:

1. Approximately 1000 acres of land must be available for expansion to a full-scale facility that would be capable of storing one-third of the total MRS system requirements of 48,000 metric tons of uranium (MTU) (99,233 canisters containing 70,402 pressurized-water reactor (PWR) and 86,462 boiling-water reactor (BWR) fuel assemblies, or the equivalent in high-level-waste canisters).

2. The area should be reasonably free of land restrictions such as utilities, roads, and power lines (certain utilities such as public power-transmission lines have dominant right-of-way).

3. The area should have minimum slope and provide for ease of construction.

These general and specific requirements were used to screen the Hanford Site. Three potential areas for open-field dry-well storage were identified and are depicted in Figure 6-1 as areas 1, 2, and 3. The three areas were ranked, and the results showed that areas 1 and 2 are virtually equal in satisfying the requirements while area 3 is rated slightly lower. In order to further differentiate among the sites, additional field studies would be required; however, area 2, a relatively level site adjacent to the 200 West area of the Hanford Site and at an elevation of about 680 feet, was chosen as the reference location for a MRS demonstration facility with open-field dry-well storage. Additional siting work would be required before a final location could be selected.

The following requirements are specific to the tunnel-rack storage concept:

1. It is estimated that 6,000,000 square feet of competent rock must be available to provide enough tunnel space to store the 48,000 MTU (99,223 canisters).

2. The rock should be as thick as possible to provide for the construction of large-diameter tunnels (40 to 60 feet). The rock must also be structurally competent for safe, reliable containment of storage modules and for economical mining.

3. The site must accommodate horizontal storage tunnels for both a demonstration facility and future expansion to a full-scale facility. No vertical shafts will be used for storage or tunnel access.

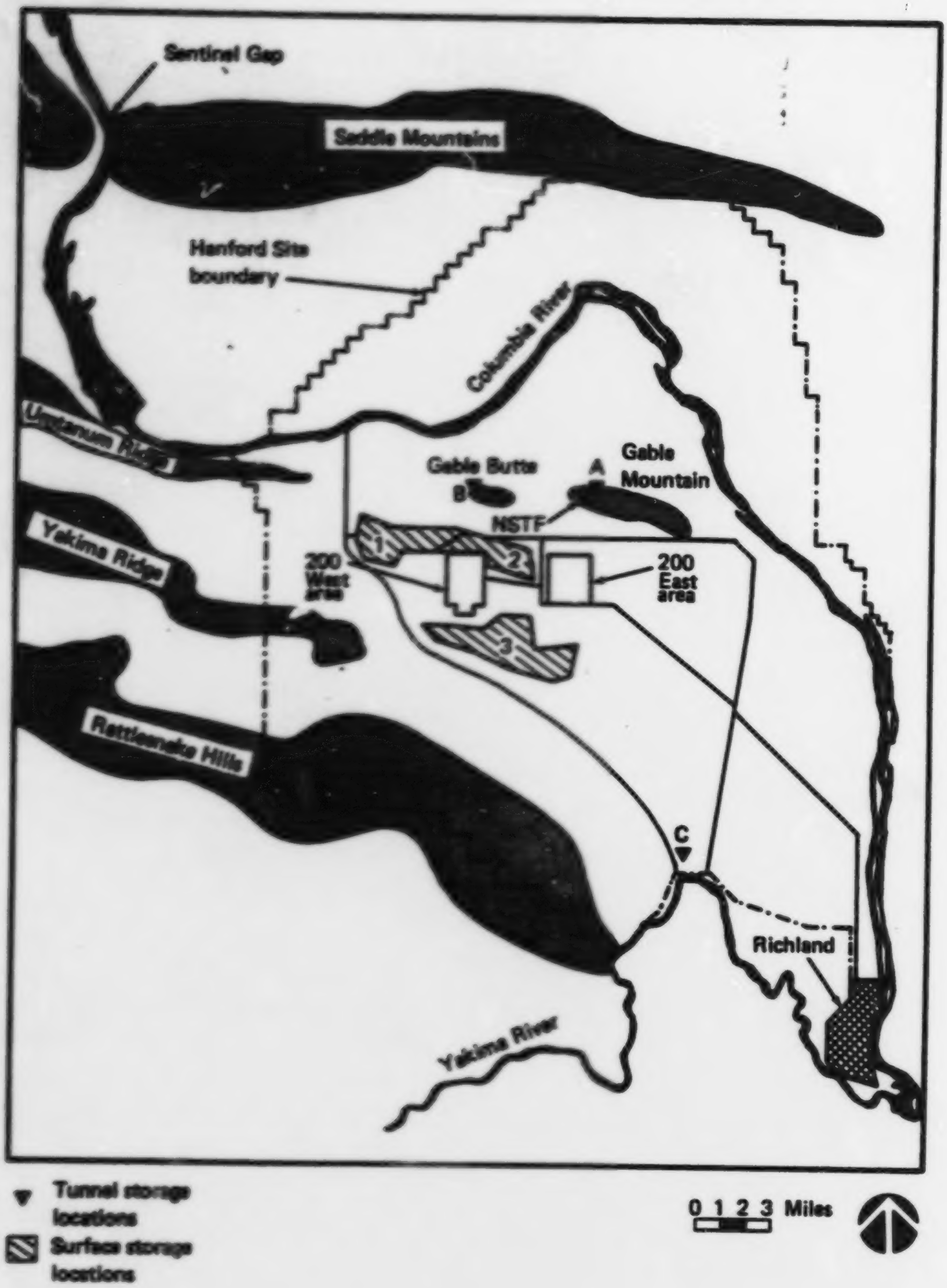

Sentinel Gap
Saddle Mountains
Hanford Site boundary
Columbia River
Umtanum Ridge
Gable Butte
B
A
Gable Mountain
NSTF
1
2
200 West area
200 East area
3
Yakima Ridge
Rattlesnake Hills
C
Richland
Yakima River
▼ Tunnel storage locations
▨ Surface storage locations
0 1 2 3 Miles

Figure 6-1. Areas of consideration for demonstration facility at Hanford.

4. The geologic profile must provide enough strata above the storage drifts for tunnel ventilation stacks and/or horizontal ventilation tunnels.

The general requirements described previously and these specific requirements were used to screen the Hanford Site. Three potential areas for tunnel-rack storage were identified and are depicted in Figure 6-1 as areas A, B, and C. Area A, in Gable Mountain, about one-half mile southeast of the existing Near-Surface Test Facility, was chosen as the reference tunnel location. Additional siting work would be required before a final location could be selected.

6.2.2 Functional requirements

The MRS demonstration facility shall provide the structures, systems, and equipment to unload, inspect, package, and place in retrievable storage PWR and BWR spent-fuel assemblies and canisters of high-level waste in a borosilicate glass medium. The facility is designed to retain the packages in retrievable dry-well storage for a period up to 100 years.

The demonstration facility shall be capable of handling, packaging, and storing an inventory of 1500 spent-fuel assemblies (50 percent PWR and 50 percent BWR) and 10 canisters of high-level waste (assumed as a representative inventory) within a 1-year period. The facility shall also be expandable in-place to a full-scale facility capable of storing about 48,000 MTU. The storage inventory will consist of 2880 fuel assemblies in 1800 packages per year for a total inventory of 156,864 fuel assemblies or equivalent in high-level waste over a loading period of approximately 55 years.

The minimum out-of-reactor age of the spent-fuel assemblies and high-level waste will be 5 and 10 years, respectively. Thermal considerations in the conceptual designs shall include upper limits of 715°F for the center pin of 5-year-old spent-fuel assemblies and 932°F for high-level waste in borosilicate glass. Nominal thermal decay heat output of a PWR spent-fuel assembly shall not exceed 1 kilowatt; the output of a BWR assembly shall not exceed 0.33 kilowatt. Thermal decay heat from a canister of high-level waste in borosilicate glass will be limited to 3 kilowatts for purposes of this study.

6.2.3 General design criteria and operational requirements

In addition to the functional requirements of Section 6.2.2, general and specific design criteria were developed for the principal facilities, systems, and major equipment. The conceptual designs of both the dry-well and tunnel-rack storage concepts include all of the systems and operating characteristics needed to satisfy these requirements and criteria. The design criteria are based primarily on the assumption that the facility would be licensed under the requirements of Title 10, Part 72, of the Code of Federal Regulations.

6.2.3.1 General design criteria

The design and performance of the facility, including systems and equipment, shall provide the following:

1. A receiving and surge storage system compatible with spent-fuel and high-level-waste acceptance criteria, shipping-cask configurations, and transport practices.
2. An encapsulation rate that will result in a facility of reasonable economic size, compatible with overall program requirements.
3. Strict accountability of spent-fuel and high-level-waste inventory.
4. Flexibility and reliability to handle damaged fuel or partial assemblies.
5. Limitation of radioactive and nonradioactive effluents to levels less than the limits specified by the appropriate regulations for normal and reasonably assumed accident conditions.
6. Limitation of radiation exposure to onsite and offsite individuals in accordance with the appropriate regulations, including Title 10, Part 20, of the Code of Federal Regulations.
7. Inclusion of an environmental monitoring system that ensures that the criteria described in 5 and 6 above can be satisfied.
8. Resistance to design-basis natural phenomena and other postulated accident events without loss of capability to perform the intended safety function.
9. Physical protection and security for the spent fuel and high-level waste in accordance with the applicable requirements of Title 10, Part 73, of the Code of Federal Regulations and the DOE Hanford Operation Security Office standards.
10. Compliance with appropriate quality standards as specified by applicable codes, standards, and regulations.
11. Compatibility with the site characteristics and environment under normal operating and test conditions.
12. Capability for decommissioning such that the site can be restored to the original condition.

6.2.3.2 Operational requirements

Detailed operational requirements for both conceptual designs were developed, and the activities involved in receiving, handling, packaging, and storing the spent fuel and high-level waste were analyzed for compliance with these requirements. These requirements were based on compliance with the functional, general design criteria, and operational requirements described above, specific criteria as documented in a Technical Data Summary by the Savannah River Laboratories, and the operating and demonstration program experience at Hanford. The results of the analyses support the projected performance of the conceptual designs.

6.2.4 Demonstration facility conceptual design--open-field dry-well storage

The open-field dry-well storage (Rockwell, 1981) conceptual design included (1) a receiving and packaging (R&P) building, (2) support buildings and systems, (3) a dry-well storage field, (4) canisters and dry-well encasements, (5) monitoring, instrumentation, and surveillance systems, and (6) a storage and retrieval system. The conceptual design is planned so that facility costs will be minimized and temporary facilities provided where feasible. Figure 6-2 is a general rendering of the demonstration facility with dry-well storage.

The conceptual design of the demonstration facility is based on previously prepared designs (Rockwell, 1978) that were scaled down to a capacity of 1000 packages of spent fuel and 10 overpacked canisters of high-level waste in a 1-year active packaging period. However, the demonstration facility will be expandable in-place to a full-scale facility capable of handling 48,000 MTU (70,402 PWR and 86,462 BWR assemblies or equivalent amounts of commercial high-level waste). The demonstration facility will accept only truck shipments, but the full-scale facility will also accept rail shipments. Both the demonstration facility and the expanded full-scale facility will meet Federal, state, and local licensing requirements.

Receiving and packaging building

The R&P building will be a multilevel, reinforced concrete, missile-resistant structure with 177,000 square feet of floor area. The concrete thickness will vary depending on the specific design requirements for radiation shielding and seismic/tornado and dead-and-live structural loads.

Approximately 37 percent of the floor area will consist of operation areas for cask receiving and cooldown, unloading, and packaging. The following are the important elements in providing these operations:

1. Three parallel truck and cask receiving air locks and dock unloading stations to accommodate about 23 truck

BEST DOCUMENT AVAILABLE

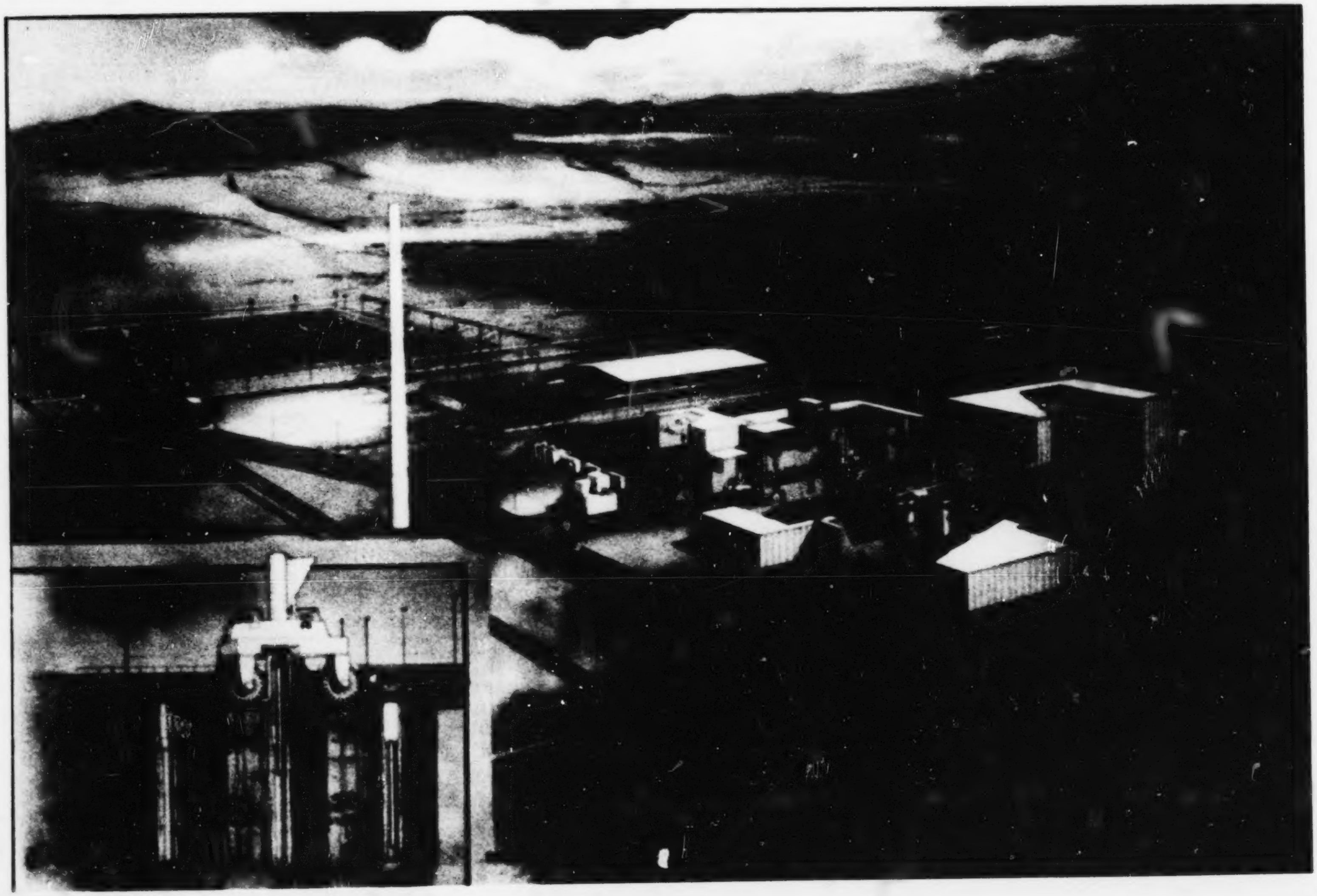


Figure 6-2. MRS demonstration facility with dry-well storage at Hanford.

shipments per week; two cask cooldown-unloading-decontamination lines, each including a dry-cask cooldown pit, a wet-cask unloading pit, and an empty-cask decontamination pit; provision for the future addition of tracks for railcar cask shipments.

2. A 95-MTU lag storage pool.
3. Three air driers for spent-fuel assemblies and waste canisters.
4. A weld-and-test packaging cell.
5. A special function, two-compartment cell for the repair of defective canisters and for the special handling of leaking or damaged fuel assemblies and high-level-waste canisters.

The remaining 63 percent of the floor area in the R&P building will accommodate the waste treatment, ventilation exhaust-filtration, administration, health physics and training personnel, material storage, auxiliary mechanical and electrical equipment and systems, and maintenance in support of the handling and packaging operations.

The R&P building can be expanded in-place by the addition of cask preparation and receiving air locks and cask unloading lines, another weld-and-test cell, and a load-out station.

The future addition of a rail connection to an existing rail line near the site of the MRS demonstration facility will accommodate trackage for railcar delivery of spent-fuel and high-level-waste shipping casks to the R&P building.

Support buildings and structures

The MRS demonstration facility onsite support buildings and structures will include administration, warehouse, and emergency generator buildings; two gatehouses; a boilerhouse; fuel oil storage tanks; an electrical substation; a 330-foot-high ventilation exhaust stack; perimeter/interior exclusion fencing; and area lighting. Existing facilities will be used to the maximum extent possible.

The administration building will consist of 12 trailer units that are already at the Hanford Site. The existing security building serving the 200 West area will also be used by the MRS demonstration facility. Additions to this security building will include security and fire-alarm monitoring systems and in-plant and commercial radio and telephone communication systems.

The MRS demonstration facility will also rely on the existing 200 West area facilities for equipment maintenance, including transport vehicle maintenance, fire station services, and health physics services outside the facility perimeter fencing, and utilities such as water supply and normal electrical power supply. Transporter cask servicing will be provided in the R&P building.

Dry-well storage area

The 1000 packages containing spent-fuel assemblies and 10 packages (overpacks) containing canisters of high-level waste will be stored in dry wells located in an 18-acre site adjacent to the southwest corner of the MRS demonstration facility as shown in Figure 6-2. The dry wells in the storage area will consist of vertical steel encasement vessels buried in the ground in a rectangular array at a uniform 17-foot center-to-center spacing for spent-fuel assemblies and 44-foot spacing for overpacked high-level waste. The design of the encasement vessels includes an exterior surface uniform corrosion rate of 0.004 inch per year and an interior rate of 0.001 inch per year. Figure 6-3 shows the physical characteristics of the dry wells.

The storage field will be divided into lines of dry wells with primary and secondary road systems for package transport, support equipment, and security vehicles.

The package would provide primary containment of the spent fuel and high-level waste, and the dry-well encasement will provide a secondary containment barrier. The soil around each dry well will reduce the ground-surface-level radiation dose to 0.25 mrem per hour. Loose sand placed in the dry-well encasement space above the package will complete the radiation shielding of each package. A closure cover, when welded onto the encasement vessel, will seal the package in the dry well.

The relatively low conductivity of the native sandy-loam soil would effectively transfer the 1 kilowatt of thermal decay heat from each spent-fuel package to the atmosphere. However, an 11- to 12-inch blanket of a more highly conductive material, for example, concrete, will be placed around 10 of the dry-well encasements to facilitate the transfer of the 3-kilowatt decay heat from the high-level-waste packages. The 3-kilowatt level of decay heat appears to be an approximate upper limit for this dry-well design in the soil at Hanford.

Figure 6-2 shows the dry-well field and a transporter in the process of placing a package into a dry-well encasement vessel.

Package description and design

Three types of packages will be prepared in the R&P building, namely, spent-fuel canisters containing PWR or BWR assemblies and overpacks of canistered high-level waste. Each outer canister will be a cylindrical carbon-steel vessel with corrosion allowance for a minimum of 100 years (0.001 inch per year uniform corrosion assumed). The spent-fuel canister packages will each contain either a single PWR or three BWR fuel assemblies. The

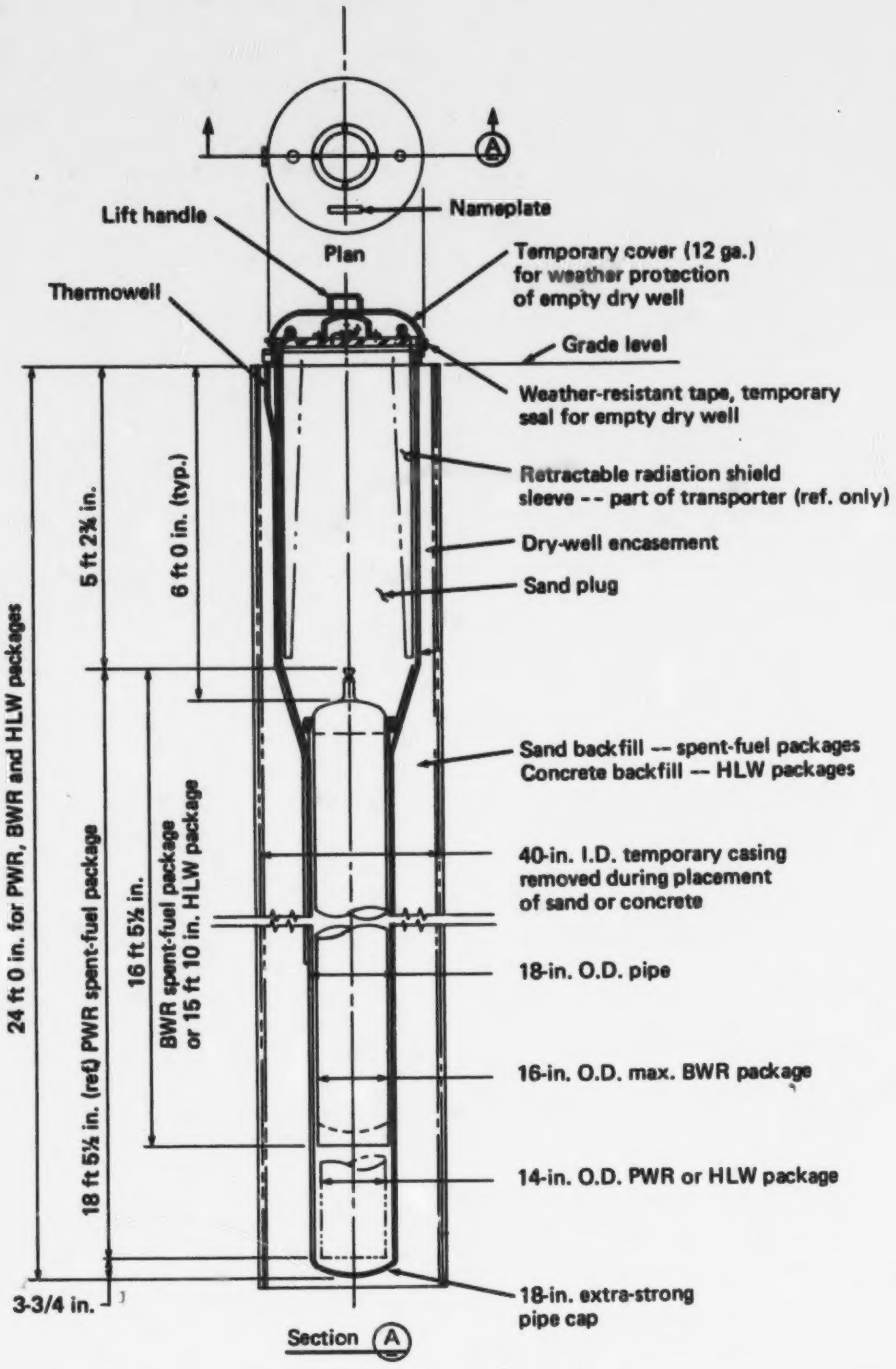

Plan
A
Lift handle
Nameplate
Temporary cover (12 ga.) for weather protection of empty dry well
Thermowell
Grade level
Weather-resistant tape, temporary seal for empty dry well
Retractable radiation shield sleeve -- part of transporter (ref. only)
Dry-well encasement
Sand plug
Sand backfill -- spent-fuel packages
Concrete backfill -- HLW packages
40-in. I.D. temporary casing removed during placement of sand or concrete
18-in. O.D. pipe
16-in. O.D. max. BWR package
14-in. O.D. PWR or HLW package
18-in. extra-strong pipe cap
24 ft 0 in. for PWR, BWR and HLW packages
5 ft 2¾ in.
6 ft 0 in. (typ.)
18 ft 5½ in. (ref) PWR spent-fuel package
16 ft 5½ in.
BWR spent-fuel package or 15 ft 10 in. HLW package
3-3/4 in.
Section A

Figure 6-3. Dry-well encasement for Hanford.

high-level-waste canister overpacks will each contain a single canister of high-level waste.

The upper cap of the package will have a lifting pintle suitable for a special handling grapple. The cap will also include a valve assembly for evacuating and then charging the package with a stabilizing gas. The valve will be permanently sealed by the insertion of a mechanical closure, followed by seal welding the closure after the gas-charging operation is completed. Figure 6-4 shows the physical characteristics of the three canisters.

Monitoring, instrumentation, and surveillance

The monitoring, instrumentation, and surveillance program will be a major consideration in the design of the MRS facility. In the R&P building, redundant instrumentation channels will be used to monitor the important waste processing and storage parameters. Radiation monitoring and survey equipment will be provided to indicate airborne activity, penetrating radiation, and contaminated personnel or material. Three types of monitors will be used: area gamma monitors, beta-gamma particulate monitors, and thermoluminescent dosimeters. In addition, special personnel and vehicle monitoring equipment, including radiation sensors, will be provided at the main gatehouse of the facility.

Onsite and offsite radiation monitoring will be provided outside the buildings to ensure that radiation levels and airborne particulate levels do not exceed preset limits for the protection of both the staff and the public. Perimeter radiation monitors will be placed strategically around the outside boundary of the site.

In the dry-well storage field, the package in each dry well will be monitored and kept under surveillance throughout its storage life. The monitoring and surveillance operations will verify that the storage conditions are maintained and the integrity of the dry wells is not compromised or breached. The monitoring will include temperature and pressure measurement and sampling for the presence of the canister stabilizer or radioactive gases.

The proposed monitoring and surveillance schedule will be based on the potential for thermal stresses in the dry-well encasement vessel. The pressure in the encasement vessel and the temperature of the encasement wall are expected to rise quickly during the first year of package storage, slowly reach a maximum in 5 to 7 years, and then decrease with time. Therefore, the frequency of monitoring and surveillance will be greater during the early years of storage.

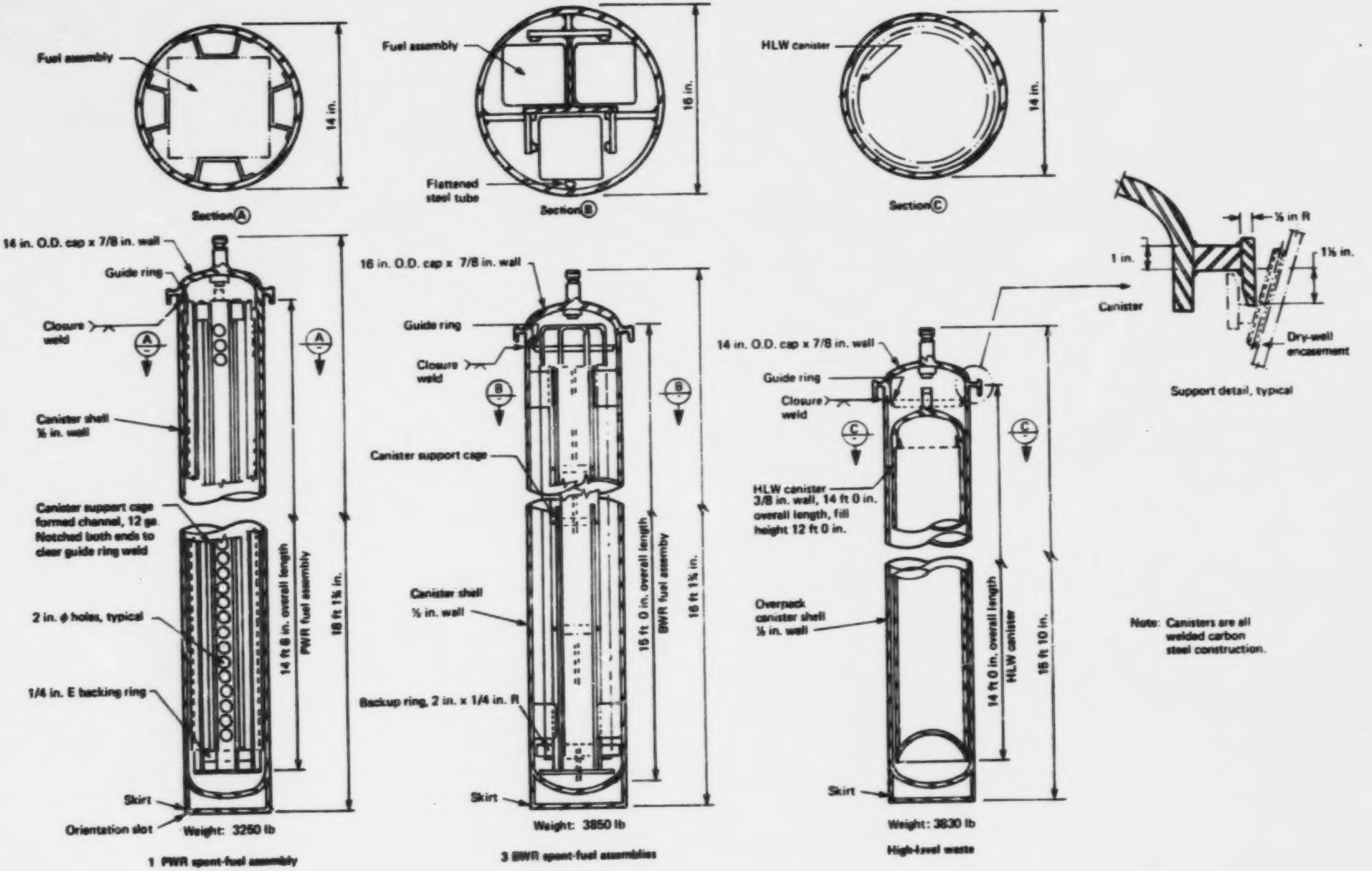

Fuel assembly
14 in.
Section Ⓐ
14 in. O.D. cap x 7/8 in. wall
Guide ring
Closure weld
Ⓐ
Canister shell ½ in. wall
Canister support cage formed channel, 12 ga. Notched both ends to clear guide ring weld
2 in. ϕ holes, typical
1/4 in. E backing ring
14 ft 8 in. overall length PWR fuel assembly
18 ft 1½ in.
Skirt
Orientation slot
Weight: 3250 lb
1 PWR spent-fuel assembly
Fuel assembly
Flattened steel tube
16 in.
Section Ⓑ
16 in. O.D. cap x 7/8 in. wall
Guide ring
Closure weld
Ⓑ
Canister support cage
Canister shell ½ in. wall
Backup ring, 2 in. x 1/4 in. R
15 ft 0 in. overall length BWR fuel assembly
16 ft 1½ in.
Skirt
Weight: 3850 lb
3 BWR spent-fuel assemblies
HLW canister
14 in.
Section Ⓒ
14 in. O.D. cap x 7/8 in. wall
Guide ring
Closure weld
Ⓒ
HLW canister 3/8 in. wall, 14 ft 0 in. overall length, fill height 12 ft 0 in.
Overpack canister shell ½ in. wall
14 ft 0 in. overall length HLW canister
15 ft 10 in.
Skirt
Weight: 3830 lb
High-level waste
½ in R
1 in.
1½ in.
Canister
Dry-well encasement
Support detail, typical
Note: Canisters are all welded carbon steel construction.

Figure 6-4. Conceptual design of waste containers for Hanford.

Receiving and packaging operations

The following normal and routine operations are the same for both the dry-well and tunnel-rack storage systems:

1. The spent-fuel or high-level-waste shipping vehicle (truck-trailer) and cask are inspected and monitored before entering the R&P building.

2. After clearance by the inspection station, vehicle and cask enter one of three R&P building cask preparation air locks.

3. In the preparation air lock, peripheral shipping equipment is removed from around the cask. Radiation monitoring and limited washdown are performed for the removal of road dirt and the trailer and cask are moved into a cask load/off load dock.

4. The cask is transferred by overhead crane from the trailer to one of two wet receiving areas for external cask wash, cask cooldown, cask exterior-interior contamination tests, and the removal of the outer cask cover.

5. The cask is next transferred by crane to one of two water-filled pools for the removal of fuel assemblies or high-level-waste canisters.

6. After testing for leakage and monitoring for activity and thermal level, assemblies or canisters are transferred underwater in special storage baskets to a lag storage pool. (The empty cask is moved to one of two decontamination pits for inspection, washdown, and return to a shipping vehicle.)

7. Spent-fuel assemblies or high-level-waste canisters, on a scheduled basis, are moved underwater to the weld-and-test cell, air-dried, and placed in a canister for packaging.

8. Weld-and-test cell packaging operations consist of the following steps:

   a. Weld the cap on the canister containing one PWR or three BWR spent-fuel assemblies or one high-level-waste canister (overpack operation).

   b. Heat treat each cap weld joint by controlled electric induction heating.

   c. Nondestructively test each cap weld joint by ultrasonic processes with the weld joint area immersed in a water coupling medium.

d. Pressurize each canister or overpack with an inert gaseous media to a pressure of two atmospheres (absolute); close and seal-weld the pressurizing connection.

e. Test each canister or overpack for leakage of the inert gas to verify quality of the weld joint. Leakage measurement will be performed with a mass spectrometer.

f. Test each package (canister or overpack) for surface contamination by swipe tests.

g. Decontaminate packages, as required, by immersion in suitable agitated solutions, dry, and test again for the removal of contamination.

h. Remove (load-out) the completed packages from the cell into a shielded transfer cart.

9. Dry-Well Storage:
The shielded transfer cart and a transporter vehicle are aligned with the load-out port, and the package is transferred from shielded cart to transporter cask for delivery to the dry well.

Tunnel-Rack Storage:
The package is transferred into a tunnel-rack interface building hot cell for remote placement in rack and delivery to storage in tunnel.

Storage and retrieval operations

The spent-fuel assembly and high-level-waste packages would be transported from the R&P building load-out station to the dry-well storage field in a rubber-tired, shield-cask transporter vehicle. The sequence of package placement operations will be in three major steps: (1) dry-well preparation, (2) package placement and completion of placement with a sand-shield fill, and (3) welding of the steel cover plate onto the encasement vessel to seal the package in its dry well.

Package retrieval may take place at any time during the 100-year storage period. In general, the retrieval operations will amount to a reversal of the storage operation and will be performed with the transporter vehicle used in the storage operation.

6.2.5 Demonstration facility conceptual design--tunnel-rack storage

The conceptual design for tunnel-rack storage includes (1) an R&P building, (2) an interface building, (3) support buildings and systems, (4) tunnel storage, (5) canisters, (6) monitoring, instrumentation, and surveillance systems, and (7) a storage and retrieval system. The conceptual design was developed such that facility costs will be held to a minimum and temporary facilities provided where feasible. Figure 6-5 shows a general rendering of the MRS demonstration facility with tunnel-rack storage.

The conceptual design of the demonstration facility is based on a storage concept developed by the General Atomic Company (General Atomic, 1981). A single storage drift would accommodate up to 2500 packages, although the demonstration facility output is limited to 1010 packages. However, the demonstration facility can be expanded in-place, by the construction of additional tunnels and storage drifts, to a full-scale facility capable of handling 48,000 MTU (70,402 PWR and 86,462 BWR assemblies, or equivalent amounts of commercial high-level waste). The demonstration facility would accept only truck shipments, but the full-scale facility would also accept rail shipments. Both the demonstration facility and a full-scale facility will meet Federal, state, and local licensing requirements.

Receiving and packaging building

The R&P building would be as shown in Figure 6-2 except for the integration of a tunnel-rack interface building with the south wall and load-out station of the R&P building shown in Figure 6-5.

The future addition of a rail connection to the existing rail line near the 200 West area would be required to accommodate trackage for rail-car delivery of spent-fuel and high-level-waste shipping casks to the R&P building.

Interface building

The interface building, shown in the center of Figure 6-5, would be a reinforced-concrete, missile-resistant structure similar in construction to the R&P building. It will have a floor area of approximately 46,000 square feet of which 23 percent would consist of a shielded rack-loading hot cell and a tunnel entry section. Approximately 50 percent of the building would be devoted to rack receiving, storage, and decontamination. The remaining 27 percent would include a control room and mechanical/electrical equipment and system areas.

Spent-fuel and high-level-waste packages leaving the R&P building via its weld-and-test cell load-out transfer tunnel will enter the interface building rack-loading hot cell through an opening(s) in the floor of the hot cell.

In the hot cell, packages would be remotely loaded into special storage racks, each capable of storing 50 PWR, BWR, or high-level-waste packages. When 50 canisters have been accumulated in a rack (approximately every 2.5 weeks), the rack will be placed on a rail-mounted, electrically driven rack transporter and remotely transferred through a main entry tunnel to one of two storage drifts in Gable Mountain.

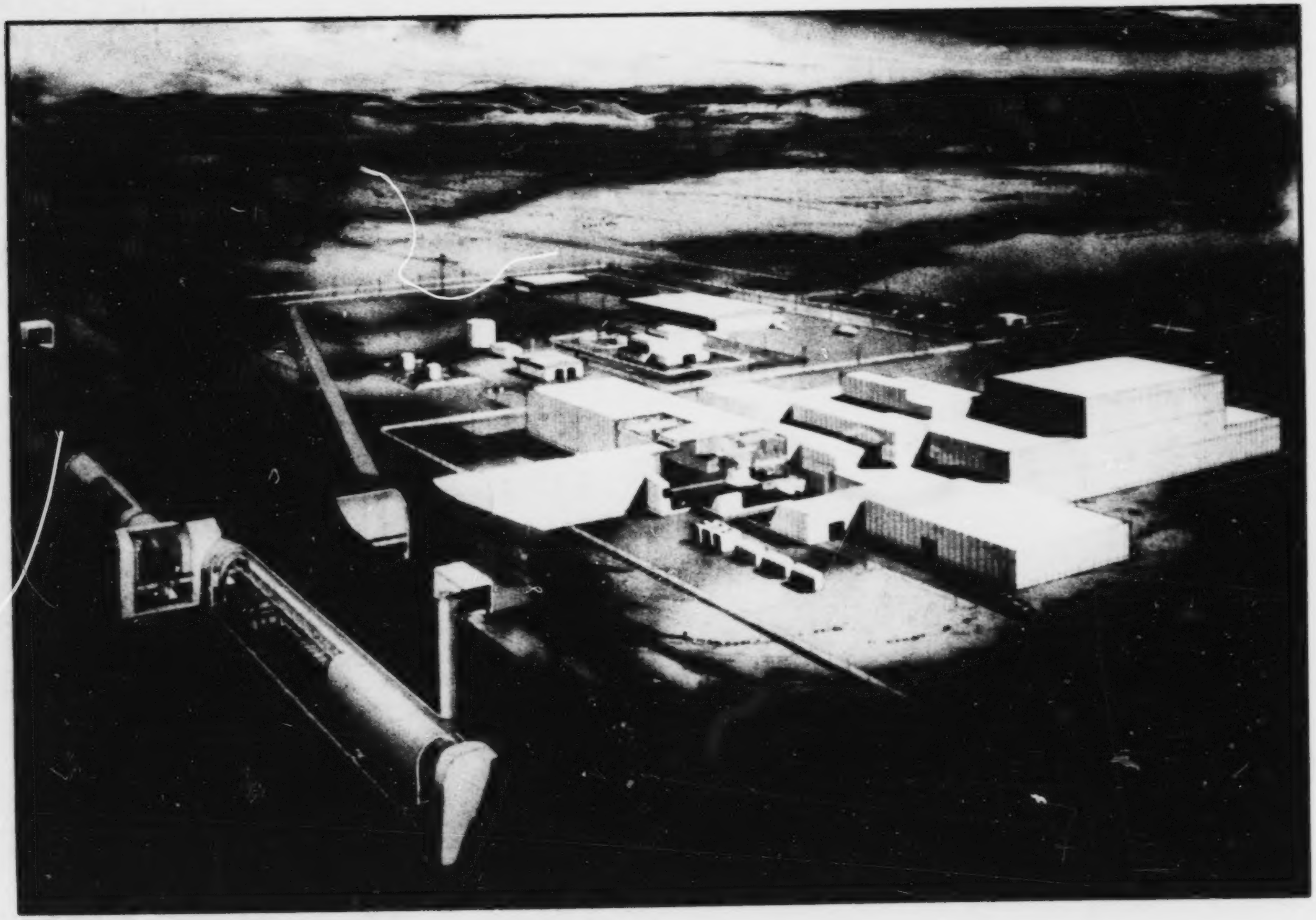


Figure 6-5. MRS demonstration facility with tunnel-rack storage at Hanford.

When the transporter is in position at the entrance to one of the drifts, a diesel or battery-operated, remotely controlled locomotive will be used to push the rack loaded with packages along a four-rail track (two outer rails for the rack transporter and two inner rails for the locomotive) into a permanent storage position in a 500-foot-long, reinforced-concrete, arch-roof storage module located within the drift. The transporter will then lower the rack onto corbels (ledges) located along each side of the module. The locomotive and transporter will be returned to the interface building to await another loaded rack.

The recommended full-scale design loading and storage rate for an MRS facility is 1800 packages per year, based on a mix of 540 BWR and 1260 PWR packages containing a total of 2880 spent-fuel assemblies. The package-handling rate in the interface hot cell can be increased to meet these requirements for a full-scale facility without any change in the design of the demonstration facility. At this rate, a rack will be loaded and placed in storage about every 1.5 weeks.

Although the interface building space and equipment can easily accommodate this loading rate, the number of storage drifts, modules, mechanical, electrical, and monitoring and control systems will have to be increased as described below. In addition, the construction of a rack transfer tunnel will be necessary as the number of drifts in Gable Mountain are increased.

Support buildings and structures

Although arranged in a different configuration on the site, the support buildings and structures for an MRS demonstration facility with tunnel-rack storage will be essentially the same as those described earlier for dry-well storage, except that only one gatehouse will be required.

Tunnel storage

The MRS demonstration facility will be located as shown in Figure 6-5. The topography shall be gently sloping to a steeply rising hill underlain by sound rock with a stable front face, providing portal access to the storage area.

The facility will consist of one concrete-lined main tunnel 45 feet wide by 50 feet high by 800 feet long with two connecting drifts. Each drift will be 36 feet wide by 47 feet high by 557 feet long. The drifts will enclose insulated prestressed concrete modules that are designed for rack storage. The ventilation air exhaust from the drifts will be vented to 16 feet in diameter by 125 feet high vertical stacks with radiation shielding outlet structures at the top of each stack as shown in Figure 6-5. Cooling of the canisters will be provided by the passage of air through the storage drift and up the vertical stacks. Ventilation is provided by the transfer of heat from the packages to the air.

Package description and design

Three types of packages will be prepared in the R&P building, namely, spent-fuel canisters containing PWR or BWR assemblies and overpacks of canistered high-level waste. Each outer canister will be a cylindrical carbon steel vessel. The spent-fuel canister packages will each contain either one PWR or three BWR fuel assemblies. The high-level-waste canister overpacks will each contain a single canister of high-level waste.

The upper cap of the package will have a lifting pintle suitable for a special handling grapple. The cap will also include a valve assembly for evacuating and then charging the package with a stabilizing gas. The valve will be permanently sealed by the insertion of a mechanical closure followed by seal-welding the closure after the gas-charging operation is completed. Figure 6-4 shows the physical characteristics of the three canisters.

Monitoring, instrumentation, and surveillance

The monitoring, instrumentation, and surveillance program will be a major consideration in the design of the MRS facility. In the R&P building, redundant instrumentation channels will be used to monitor the important waste processing and storage parameters.

Radiation monitoring and survey equipment will be provided to indicate airborne activity, penetrating radiation, and contaminated personnel or material. Three types of monitors will be used: gamma monitors, beta-gamma particulate monitors, and thermoluminescent dosimeters.

Onsite and offsite radiation monitoring will be provided outside the buildings to ensure that radiation levels and particulate levels do not exceed preset limits.

In the tunnel, the canister will be monitored and kept under surveillance throughout its storage life. The monitoring and surveillance operations will verify that the storage conditions are maintained and the integrity is not compromised or breached. The monitoring parameters will include temperature and pressure and the presence of the canister stabilizer or radioactive gases.

Each canister will be pressurized with a gas that can be detected in small quantities; in addition, each canister head will contain a thermowell with an indicator that rises with loss of pressure in the event of canister leakage. Visual observation of each canister indicator will be afforded with the use of a television camera mounted on a monorail traversing the length of each drift; each stack will contain a continuously monitoring sensing probe.

Storage and retrieval system

The arrangement of the tunnel-rack concept interface facility is contiguous with the R&P building. The spent-fuel and high-level-waste canisters will be loaded into storage racks for placement into the storage drifts. The placement of the storage racks will be accomplished with a bridge transporter for movement through main tunnels and a control car and rack transporter for rack placement inside the module. Figure 6-6 illustrates a typical application.

The recovery vehicle is a radio-controlled tracked vehicle that is able to operate independently of the rail system in the main tunnels, storage drifts, or the loading cell. It will be powered by a portable battery power supply. It will also afford additional monitoring, detailed visual inspection of in-tunnel equipment and canisters, recovery of disabled equipment, television camera adjustment, and light fixture replacement.

6.2.6 Capital cost estimates for Hanford

The capital cost estimates for the MRS demonstration facility at Hanford include the engineering design, construction, and outfitting of the facility required for the packaging and storage of spent-fuel assemblies and canisters of high-level waste.

Current union rates at Hanford, Washington, were used in estimating the cost of construction labor. An allowance of 5 percent was added for casual overtime. The direct construction costs for the facility were increased to allow for general contractor field overhead and profit and home office support. The allowance included an estimated 30 percent on labor and equipment usage, 13 percent on material, and 10 percent on equipment. In addition, the Titles I, II, and III engineering design and inspection services and onsite program administration, estimated at 25 percent of the construction costs, were included in the capital cost estimate. A contingency of 20 percent has been applied to the cost of construction, installation, engineering design, and inspection.

Because a date for the initiation of the engineering design has not been established, escalation to the mid-point of construction has not been included in the estimate.

A breakdown of the capital cost of the MRS demonstration facility with dry-well storage at the Hanford Reservation, estimated at $245 million in mid-1981 dollars, is shown in Table 6-1; a breakdown for tunnel-rack storage at Hanford, estimated at $341 million in mid-1981 dollars, is shown in Table 6-2.

Capital and operating and maintenance costs for an expanded full-scale facility are discussed in Section 2.4.2.2.

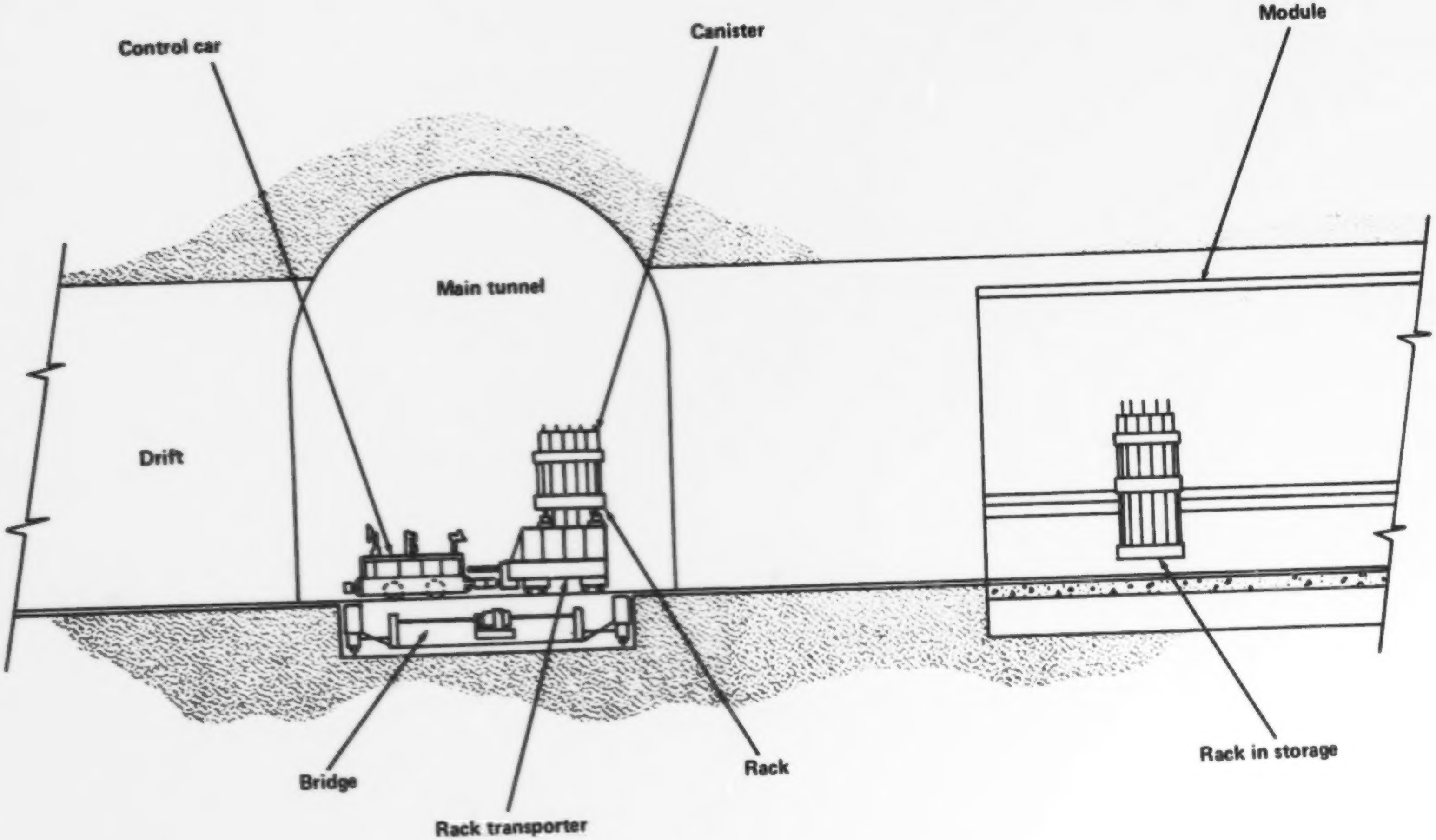

Control car
Canister
Module
Main tunnel
Drift
Bridge
Rack transporter
Rack
Rack in storage

Figure 6-6. Schematic diagram of tunnel-rack storage.

Table 6-1. Cost estimate for an MRS demonstration facility with open-field dry-well storage at Hanford

Cost category	Amount	Rounded totals
Receiving and packaging (R&P):		
Improvements to land	$ 3,500,000	
R&P building	123,100,000	
Auxiliary buildings	10,000,000	
Miscellaneous structures, including stack	2,000,000	
Area and site perimeter instrumentation, communications, and alarm	1,800,000	
Utilities	6,600,000	
Standard equipment	800,000	
Subtotal	$147,800,000	
Engineering design and inspection at 25 percent of construction costs	37,000,000	
Subtotal	$184,800,000	
Canisters	5,000,000	
Subtotal	$189,800,000	
		$190,000,000
Open-field dry-well storage:		
Improvements to land	$ 310,000	
Auxiliary buildings	170,000	
Mechanical equipment, including maintenance and security vehicles	1,293,000	
Transporter	1,200,000	
Dry-well encasements	9,491,000	
Area and site perimeter instrumentation, communications, alarm, and monitoring vehicles	832,000	
Utilities	128,000	
Subtotal	$ 13,424,000	
Engineering design and inspection at 7 percent of construction costs	940,000	
Subtotal	$ 14,364,000	
		$ 14,000,000
Subtotal--MRS with open-field dry-well storage		$204,000,000
Contingency at 20 percent		41,000,000
Total--MRS with open-field dry-well storage		$245,000,000

Table 6-2. Cost estimate for an MRS demonstration facility with tunnel-rack storage at Hanford

Cost category	Amount	Rounded totals
Receiving and packaging (R&P):		
Improvements to land	$ 3,900,000	
R&P building	123,100,000	
Auxiliary buildings	10,000,000	
Miscellaneous structures, including stack	2,000,000	
Area and site perimeter instrumentation, communications, and alarm	1,800,000	
Utilities	7,900,000	
Standard equipment	800,000	
Subtotal	$149,500,000	
Engineering design and inspection at 25 percent of construction costs	37,400,000	
Subtotal	$186,900,000	
Canisters	5,000,000	
Subtotal	$191,900,000	$192,000,000
Tunnel-rack storage:		
Interface building	$ 42,800,000	
Tunnel storage	30,400,000	
Subtotal	$ 73,200,000	
Engineering design and inspection at 25 percent of construction costs	18,300,000	
Subtotal	$ 91,500,000	$ 92,000,000
Subtotal--MRS with tunnel-rack storage		$284,000,000
Contingency at 20 percent		57,000,000
Total--MRS with tunnel-rack storage		$341,000,000

[redacted]

6.3 Conceptual designs for the Nevada Test Site

Detailed conceptual designs for dry-well storage in open fields and in tunnels were developed for the monitored retrievable storage of spent fuel in an arid region of the United States (Westinghouse, 1981). The site characteristics and data for the designs were based on areas of the Nevada Test Site. A storage capacity of 10,000 MTU of spent fuel was used. This capacity allowed for reasonable scaling of costs and schedule for a full-scale facility to store approximately 48,000 MTU of spent fuel and for a demonstration facility to emplace 2000 canisters in a 2-year period.

6.3.1 Siting

The site requirements for these two concepts are quite different. However, the following general requirements apply to both concepts:

1. Facilities must be located on the Nevada Test Site.
2. Facilities must be located so as not to interfere with the operations of existing facilities. (This requirement limits the area of consideration to the southwest corner of the Nevada Test Site.)

Specific site requirements for the open-field dry-well concept are as follows:

1. Approximately 425 acres of land must be available for expansion to a full-scale facility that would be capable of storing approximately one-third of the total MRS system requirements of 48,000 MTU (113,633 dry wells containing 70,402 PWR and 86,462 BWR fuel assemblies).
2. The area should be reasonably free of land restrictions such as utilities, power lines, and existing roads.
3. The area should have minimum slope and provide for ease of construction.

These general and specific requirements were used to identify an area for the conceptual design. The area that satisfied these requirements was Jackass Flats in the southwest corner of the Nevada Test Site.

The following requirements are specific to the tunnel dry-well storage concept:

1. Approximately 2700 acres of competent rock must be available to provide enough tunnel space to store approximately 48,000 MTU of spent fuel (113,633 dry wells).
2. The rock medium must be capable of dissipating the thermal load and must be structurally competent for safe,

economical mining and reliable protection of the waste packages.

3. The site must accommodate horizontal storage tunnels for both a demonstration facility and future expansion to a full-scale facility. No vertical shafts will be used for storage or tunnel access.

These general and specific requirements were used to evaluate potential locations for dry-well storage in tunnels in the southwestern portion of the Nevada Test Site. The area that met these requirements was Yucca Mountain. While there is no existing land-use conflict at this location now, there may be one in the future because Yucca Mountain is under active investigation for a geologic repository.

6.3.2 Functional requirements

The MRS demonstration facility shall provide the structures, systems, and equipment to unload, inspect, package, and place in retrievable storage PWR and BWR spent-fuel assemblies and encapsulated high-level waste. The facility is designed to retain the packages in retrievable dry-well storage for a period up to 100 years.

The demonstration facility shall be capable of handling, packaging, and storing an inventory of 1333 spent-fuel assemblies (50 percent PWR and 50 percent BWR) and 1000 canisters of high-level waste (assumed as a representative inventory) within a 1-year period. The facility shall also be expandable in-place to a full-scale facility capable of storing approximately 48,000 MTU. The total storage inventory will consist of 70,402 PWR and 86,462 BWR spent-fuel assemblies or equivalent high-level waste loaded over a period of approximately 55 years.

The minimum out-of-reactor age of the spent-fuel assemblies and high-level waste will be 5 and 10 years, respectively. Thermal considerations in the conceptual designs shall include upper limits of 715°F for the center pin of 5-year-old spent-fuel assemblies and 932°F for high-level waste in borosilicate glass. Nominal thermal decay heat output of a PWR spent-fuel assembly shall not exceed 1 kilowatt; the output of a BWR assembly shall not exceed 0.33 kilowatt. It is assumed that the dimensions of the encapsulated high-level waste will be compatible with the standard storage package and handling equipment for the facility.

6.3.3 General design criteria and operational requirements

In addition to the functional requirements of Section 6.3.2, general and specific design criteria were developed for the principal facilities and major equipment. The conceptual designs of both the open-field dry-well and tunnel dry-well concepts include all of the facilities and operating characteristics needed to satisfy these requirements and criteria. The design criteria are based primarily on the assumption that the facilities would be licensed under the requirements of Title 10, Part 72, of the Code of Federal Regulations.

6.3.3.1 General design criteria

The design and performance of the facility, including systems and equipment, shall provide the following:

1. Compliance with appropriate quality standards as specified by all applicable codes, standards, and regulations.
2. Compatibility with the site characteristics and environment under normal operating and test conditions.
3. Resistance to design-basis natural phenomena and other postulated accident events without loss of capability to perform the intended safety function.
4. Prevention of an inadvertent criticality event under all normal and reasonably assumed accident conditions.
5. Limitation of releases of radioactive and nonradioactive effluents to levels less than the limits specified by the appropriate regulations for normal and reasonably assumed accident conditions.
6. Limitation of radiation exposure to onsite and offsite individuals in accordance with the appropriate regulations, including Title 10, Part 20, of the Code of Federal Regulations.
7. Inclusion of an environmental monitoring system that ensures that the criteria described in 5 and 6 above can be satisfied.
8. Capability for decommissioning such that the site can be restored to unrestricted public access.
9. Physical protection and security for the spent fuel in accordance with the applicable requirements of Title 10, Part 73, of the Code of Federal Regulations.

6.3.3.2 Operational requirements

Detailed operational requirements and procedures were developed for both conceptual designs for all significant activities involved in receiving, handling, packaging, and storing the spent fuel. The selection of specific equipment, components, and processes used in the conceptual designs was based on current day storage technology developed during demonstration programs at the Nevada Test Site (Rockwell, 1978, 1981; General Atomic, 1981; Westinghouse Electric, 1981).

6.3.4 Demonstration facility conceptual design--open-field dry-well storage

Both the open-field and tunnel storage concepts consist of three basic systems: (1) an R&P system, (2) a transport system, and (3) a storage system using dry wells. The R&P building (Figure 6-7), which is identical for both concepts, receives spent-fuel assemblies in shipping casks and incorporates all the steps and processes necessary to encapsulate the fuel assemblies in storage canisters. The transport system, common to both concepts, consists of the vehicles and casks necessary to move the encapsulated waste from the receiving and packaging facility to the storage area and place the canistered waste in dry wells. The dry-well design is similar for both the open-field and the tunnel storage concepts.

Receiving and packaging building

The R&P packaging building, which occupies approximately 32,000 square feet of land, contains the principal operating equipment for shipping-cask unloading and spent-fuel encapsulation. The conceptual building design includes two independent waste package processing lines. For the demonstration facility, only one process line will be equipped. For the full-scale facility, both process lines will be activated to accommodate approximately 1800 storage packages per year.

The receiving and packaging building has four basic functional areas: a cask receiving bay, two process cells with operating galleries and supporting operations, a personnel services bay, and a cold shop bay.

The receiving bay is a steel-frame structure with a 135-ton bridge crane and other equipment necessary for handling all currently licensed shipping casks. Sufficient truck cask shipments can be accommodated in the receiving bay and adjacent cask preparation area to satisfy the demonstration facility storage requirements. With the addition of a rail connection, the facilities, as designed, could accommodate sufficient truck and rail cask shipments to sustain the storage rate requirements for a full-scale facility.

The process cell portion of the receiving and packaging building is a reinforced concrete structure with provisions for eventually accommodating two independent processing lines separated by a common operating gallery. The shielded area within each process cell is 1400 square feet. A shielded area, separated from the process cells, is provided to allow active maintenance of cranes, manipulators, and process equipment. The process cells contain all the equipment and facilities necessary to unload the fuel assemblies from the cask and place them in canisters. All fuel-handling operations are performed in an air environment (dry). Waste encapsulation is performed by welding closure lids on the canisters using a remotely operated plasma arc-welding system.

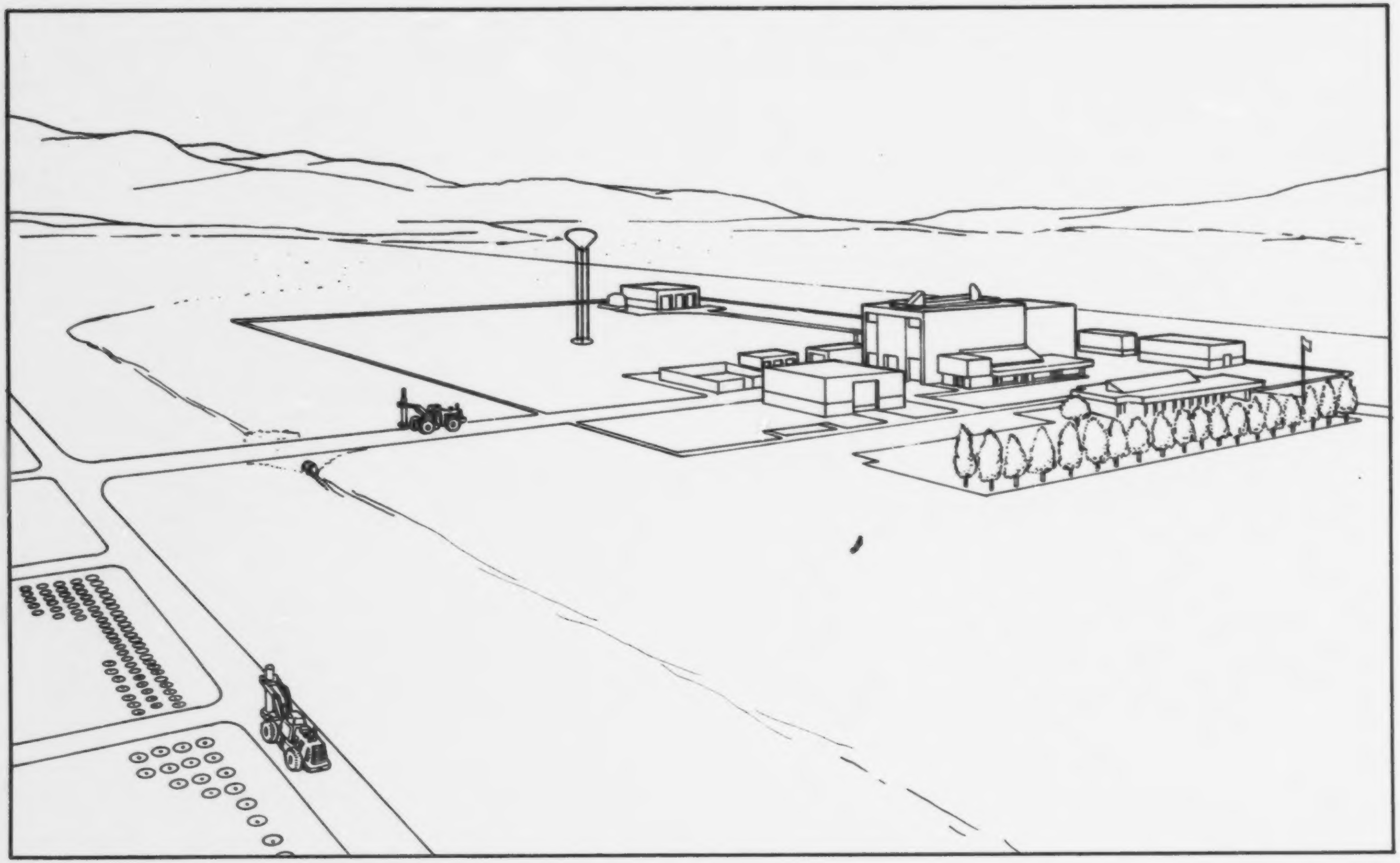


Figure 6-7. MRS demonstration facility with dry-well storage at Nevada Test Site.

Following encapsulation and weld inspection, the canister is moved to a survey station where it is checked for loose surface contamination before release from the processing cell. Fuel assemblies can be removed from the welded canisters at the canister cutting station. A shielded storage area is provided for five canisters within the process cell. Canisters are moved from the process cell to the load-out area via an underfloor transfer system. Encapsulation material is moved into the process cell using a conveyor system located below the operating gallery floor. For the demonstration facility, it is estimated that at least one encapsulation (one PWR fuel assembly or two BWR assemblies or one canister of high-level waste) can be completed per 8-hour shift, assuming only legal weight truck cask shipments and one processing line.

The personnel services bay is a steel-frame structure adjoining the process cell on the south side. This bay contains the health physics station with decontamination facilities, offices for supervisory personnel, a change room, and records processing and storage facilities.

The cold shop bay structure, located on the north side of the process cell, is similar to the personnel services bay. This bay contains the machine, electrical and instrument shops, and the tool room.

The safety systems included in the R&P building consist of environmental control, radiological monitoring, fire protection, and security.

Support buildings and structures

The administration and security control building contains offices for plant management; technical, administrative, clerical, and security personnel; a conference room; and a mechanical equipment room. A warehouse and storage yard will be located adjacent to the R&P building. The warehouse will be used for storing equipment and supplies that require environmental protection, and the remainder will be stored in the storage yard.

Cleaning systems for the shipping cask and vehicle are also provided. Vehicle washdown will be accomplished on an open concrete pad; cask washdown will be accomplished in a prefabricated metal building.

The radioactive waste building provides for the collection of liquid and solid low-level radioactive wastes from onsite sources, the solidification of ion exchange resins used in processing liquid wastes, and the compaction and packaging of solid wastes for shipment off the site.

General utility and material-handling vehicles are also available to support the receiving, encapsulation, emplacement, storage, and retrieval operations for spent fuel.

Dry-well storage area

The open-field dry-well storage area will occupy less than 10 acres adjacent to the demonstration facility to accommodate 2000 storage packages. For the full-scale facility, the storage area would be expanded to occupy approximately 400 acres. The dry wells are located in a square array with a center-to-center spacing of 10 feet to maintain acceptable fuel-rod cladding temperatures. Access roads subdivide the storage area into plots; each plot contains 441 dry wells. The site is selected, graded, and compacted to enhance the drainage of surface water and to support the cask transfer vehicle wheel loads. Dry wells are installed by drilling holes in the soil, inserting the dry-well liners, and backfilling the holes around the liner with cement grout. A concrete collar (about 5 feet in diameter and 20 inches thick) is placed at the top of the dry well. The installation of dry-well liners will occur on a continuing basis to meet the encapsulation rate.

Storage components--description and design

The components for one storage unit include a dry-well liner and cover, a canister, and a shield plug. The designs of the storage components are common to both the open-field and tunnel storage concepts. The dry-well liner installation methods differ between the two concepts because of the differences in the host geology (i.e., soil versus tuff).

The dry-well liner, as shown in Figure 6-8, consists of a section of 16-inch outside diameter (O.D.) carbon steel pipe with a wall thickness of 0.375 inch. The bottom of the liner is closed with a flat carbon steel plate welded to the liner body. After the emplacement of the storage canister, a 2-inch-thick carbon steel closure is welded to the top of the dry-well liner.

The storage canister consists of a cylindrical body, upper and lower closure caps, and internal support structures. As shown in Figure 6-9, the canister body is a section of 12.75-inch O.D. carbon steel pipe with a wall thickness of 0.33-inch. The upper and lower end caps are both fabricated from standard carbon steel pipe end caps. The specific internal support structures depend on the spent-fuel type or waste form to be encapsulated, (one PWR or two BWR fuel assemblies or one canister of high-level waste). Although a conceptual design was not developed for a high-level-waste canister, the design, as presented, could be adapted easily to this waste form.

Following the insertion of the spent fuel (one PWR assembly or two BWR assemblies) or waste form, the encapsulation is completed by welding the upper end cap to the canister body using a remotely operated plasma arc-welding system. The upper end cap design incorporates an integral lifting pintle that interfaces with a grapple used for handling the loaded canister. To complete the storage canister assembly, a 15-inch in diameter by 11-inch-high steel shielding plug is placed over the lifting pintle and rests

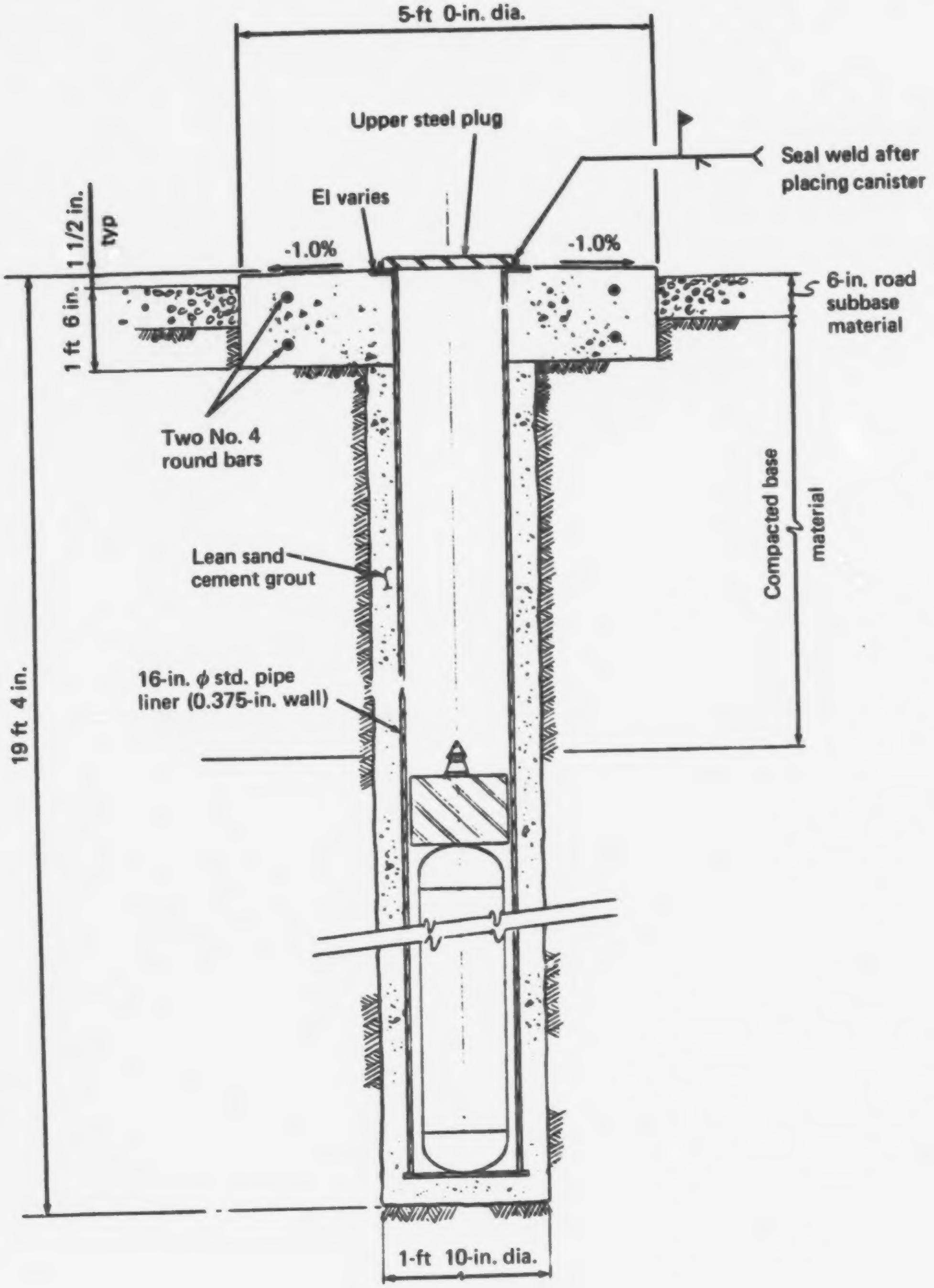

5-ft 0-in. dia.
Upper steel plug
Seal weld after placing canister
El varies
-1.0%
-1.0%
1 1/2 in. typ
6-in. road subbase material
1 ft 6 in.
Two No. 4 round bars
Compacted base material
Lean sand cement grout
16-in. ϕ std. pipe liner (0.375-in. wall)
19 ft 4 in.
1-ft 10-in. dia.

Figure 6-8. Dry-well encasement for Nevada Test Site.

[redacted]

BEST DOCUMENT AVAILABLE

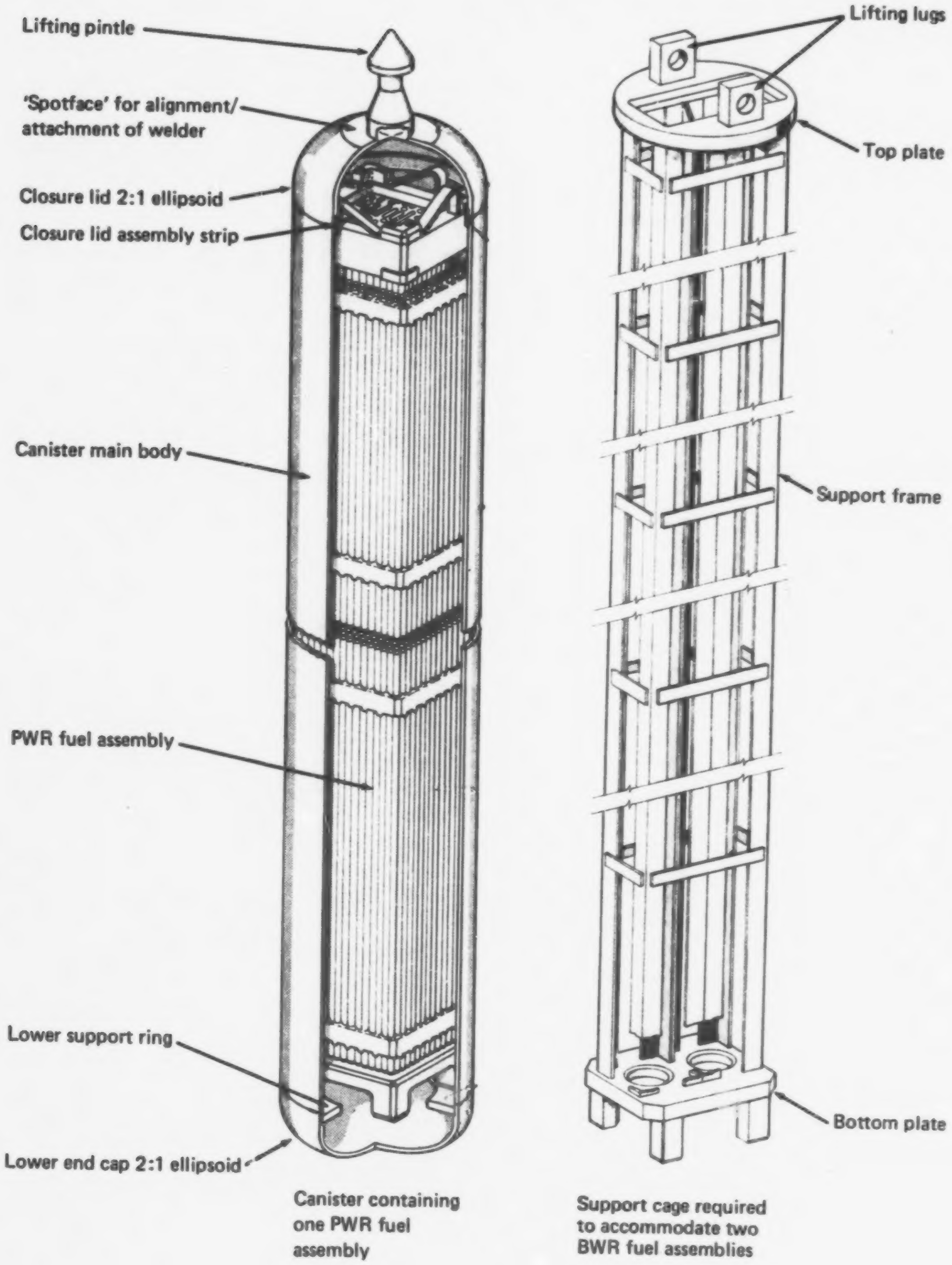

Lifting pintle
'Spotface' for alignment/ attachment of welder
Closure lid 2:1 ellipsoid
Closure lid assembly strip
Canister main body
PWR fuel assembly
Lower support ring
Lower end cap 2:1 ellipsoid
Canister containing one PWR fuel assembly
Lifting lugs
Top plate
Support frame
Bottom plate
Support cage required to accommodate two BWR fuel assemblies

Figure 6-9. Conceptual design of waste container for Nevada Test Site.

on the canister upper closure cap. The shield plug, drywell closure, and surrounding earth or rock will limit the radiation level at the surface to less than 5 mrem per hour.

For conceptual design purposes, a 0.002 to 0.003 inch per year corrosion rate was assumed for the carbon steel storage components. This corrosion rate, which must be confirmed, is consistent with known data for the expected storage environment at the Nevada Test Site.

Monitoring, instrumentation, and surveillance

The total monitoring plan for the MRS system consists of the following three types: (1) monitoring the environment of the storage site, (2) radiological monitoring within the components, and (3) monitoring the physical condition of components. The first type of monitoring will detect unexpected releases of radioactive effluent and radiation from the storage area. Environmental monitoring will be provided by a meteorological monitoring system consisting of an onsite weather tower and offsite meteorological tower; a ground-monitoring system to detect, measure, and record seismic events at the facility; and systems for measuring offsite releases of radioactive materials. The second type will detect a failure in the internal containment barriers (i.e., the dry-well liner, the storage canister, or the fuel-rod cladding). The third type will detect indications of abnormal and unexpected deterioration of physical properties so that corrective action can be taken.

The monitoring plan is based on and takes advantage of the general uniformity of the dry-well storage containers and storage areas. This uniformity allows the monitoring of a relatively small number of dry wells to provide information on a significantly larger number. The monitoring of the storage system components is performed on a periodic basis (i.e., no permanent instrumentation or air sampling connections will be installed for continuous monitoring). The monitoring of a selected dry well is accomplished by the analysis of a gas sample that is drawn through a small hole drilled in the dry-well closure lid. If fission gases were detected in the sample, the canister would be removed and returned to the packaging facility process cell for further evaluation. Visual inspection will be the primary mechanism of monitoring the physical condition of the components unless an abnormality is detected, in which case, more sophisticated physical examinations would be undertaken as required.

A security system of fences, controlled entry, and guards is provided for site surveillance.

Operations

Normal and routine spent-fuel operations would entail the following:

1. The spent-fuel shipping vehicle and cask enter the site, are inspected, washed down, and decontaminated if necessary in the cask washdown pit.
2. Vehicle and cask are moved to the cask receiving bay where the cask is transferred from the vehicle to the transfer cart in the preparation pit.
3. After appropriate preparation, the cask is moved into the process cell where it is opened and the fuel assemblies removed.
4. The fuel assemblies are inspected, moved to a weld station, and positioned in the canister. The lid is placed on the canister and welded in place.
5. The cask is removed from the process cell and after appropriate preparations and possible decontamination is returned to the shipping vehicle.
6. The fuel assemblies are inspected, moved to a weld station, and positioned in the canister. The lid is placed on the canister and welded in place.
7. Loaded canisters are transferred to a survey station, decontaminated if necessary, and moved to a lag storage area or loaded into a shielded transfer cart.
8. The shielded transfer cart and the transport vehicle shield cask are aligned with the load-out port where the canister is transferred from the shielded transfer cart to the transport vehicle shield cask.
9. The transport vehicle proceeds to the appropriate dry well, and the canister is transferred to the dry well. The dry-well cover is then seal welded.

Possible equipment malfunction and subsequent corrective action have been considered in all stages of development of the operations.

Storage and retrieval system

The storage and retrieval of canisters is accomplished with the transport system that consists of a transport shield cask and a vehicle to manipulate and move the cask. The cask is heavily shielded with a movable shield door on the bottom of the cask. The door is contained in a shield housing that provides shielding while the door is open and the canister is being transferred into or out of the cask. A grappling and hoist mechanism and a control system are the other major components of the transport shield cask.

The transport vehicle is a rubber-tired standard earth mover modified to handle the transport shield cask. The modifications consist of removing the bucket, installing the cask support/adjustment system, and adding the new controls and interlocks necessary to operate the system.

Retrieval uses the transport system and may take place at any time during the storage period; retrieval only requires a reversal of the emplacement procedure.

6.3.5 Demonstration facility conceptual design--tunnel dry-well storage

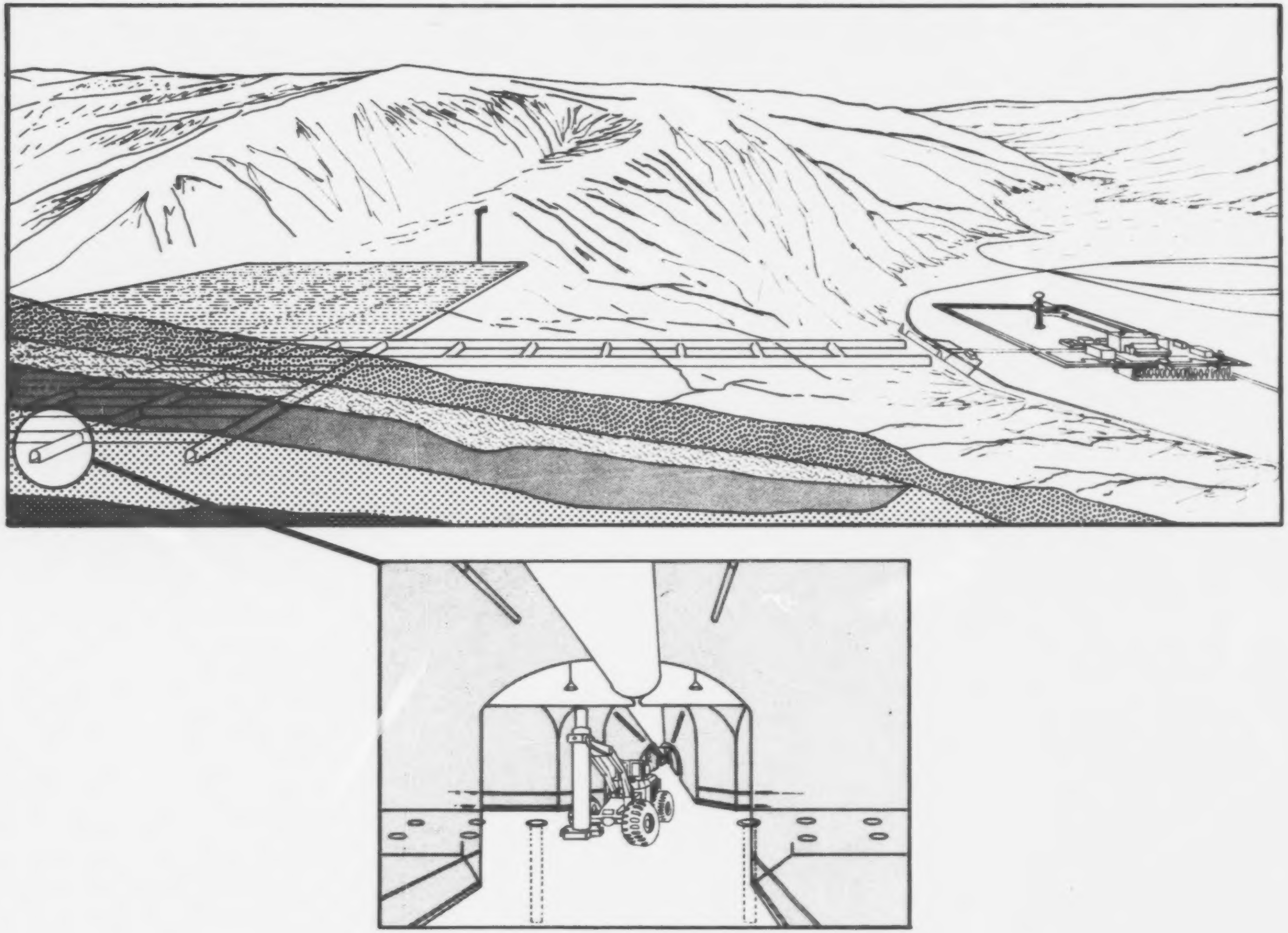
This concept will use the identical receiving and packaging and transport systems as those described above for open-field dry-well storage at the Nevada Test Site.

The plan and profile for the tunnel dry-well storage concept are shown in Figure 6-10. For the demonstration facility, the dry wells are located in the floor of 25 rooms located on opposite sides of central access tunnels. The central access tunnels consist of 2 parallel corridors 300 feet apart, extending into the side of the mountain from the tunnel entrance to the end of the underground storage area. Storage area access corridors branch off at right angles from both sides of the main access tunnels. These corridors form pillars of rock on each side of the main access tunnel. Storage rooms are separated by 140 feet of rock.

Each storage room in the tunnel dry-well concept is a 490-feet-long, 30-feet-wide, 30-foot arched ceiling excavation. Each room connects two access corridors that run perpendicular to the main access tunnels. Each room contains 80 dry wells arranged in two staggered rows of 40 dry wells each. The triangular pitch spacing between individual dry wells is 10 feet, which is enough to maintain both the rock and fuel clad temperatures below acceptable levels.

The base of the mountain that contains the tunnel storage system consists of welded and non-welded tuff, and the storage rooms are located in a stratum of welded tuff. The access tunnel portals and the R&P building are located adjacent to the base of the mountain. The tunnels and exhaust shafts are constructed by drilling and blasting. Access tunnels, crosscuts, corridors, and rooms have rock bolts and wire mesh on the walls and roof and a concrete slab floor.

The tunnel dry-well demonstration facility occupies a plan view area of about 125 acres, consisting of 60 acres for the storage rooms, access tunnels, and support facilities; 40 acres for the tunnel spoilage; and 25 acres for the R&P building. For a full-scale facility, the area required for the storage rooms, access



Tunnel view

Figure 6-10. MRS demonstration facility with tunnel dry-well storage at Nevada Test Site.

tunnels, and support facilities would expand to approximately 2700 acres.

The operations of the tunnel dry-well concept are identical to those for the open-field dry-well concept.

6.3.6 Capital cost estimates for the Nevada Test Site

The capital cost estimates include all the direct and indirect costs of providing the onsite and offsite facilities required for the demonstration installations. Capitalized cost summaries for the open-field and tunnel dry-well concepts are given in Tables 6-3 and 6-4.

6.4 Schedule

Figure 6-11 shows a possible schedule for implementation of an MRS demonstration facility, from the preparation of the functional design criteria through licensing and hot startup operations.

The figure shows the major milestone events and estimated implementation schedule, in months, and the sequence of work and activities. Each significant element of work has been identified, including the preparation of project authorization documents, engineering design, licensing, construction, and cold/hot startup. For example, the Title I and Title II engineering design is estimated to require approximately 2-1/2 years.

The overall construction period for an MRS demonstration facility with open-field dry-well or tunnel-rack storage is estimated to be 33 months. This schedule applies to all concepts except the tunnel dry-well concept at the Nevada Test Site described in Section 6.3, which would require an additional 6 months of construction. However, certain construction activities such as site rough grading, offsite electrical power transmission work, and building an access road to the site will be initiated by early procurement contracts and will overlap the completion of the Title II engineering design.

Although it is unlikely that any of the project elements of work shown in the schedule can be deleted, the calendar time for certain activities may be reduced slightly. For example, the site geology and environmental characteristics have already been well documented for government reservations like the Hanford Site and the Nevada Test Site. However, the estimated time in months shown above each bar in the schedule is considered to be a reasonable average based on previous experience in similar activities for nuclear projects.

The total storage and surveillance period for the MRS demonstration facility includes a 1-year receiving and packaging period, a maximum 100 years of first-in, first-out storage of the packaged spent-fuel elements and high-level waste, and a 1-year retrieval period. Retrieval during the final year of facility operation

Table 6-3. Cost estimate for an MRS demonstration facility with open-field dry-well storage at the Nevada Test Site

Cost category	Amount	Rounded totals
Receiving and packaging (R&P):		
Improvements to land	$ 1,486,000	
R&P building	61,504,000	
Auxiliary buildings	9,888,000	
Miscellaneous structures	1,486,000	
Area and site perimeter instrumentation, communications, and alarm	619,000	
Utilities	5,323,000	
Subtotal	$ 80,306,000	
Engineering design and inspection at 25 percent of construction costs	20,077,000	
Subtotal	$100,383,000	
Canisters	4,100,000	
Subtotal	$104,483,000	
		$104,000,000
Open-field dry-well storage:		
Improvements to land	$ 527,000	
Auxiliary buildings	0	
Maintenance and security vehicles[a]	1,059,000	
Transporter (including shield cask)	917,000	
Dry-well fabrication and installation	5,212,000	
Area and site perimeter instrumentation, communications, and alarms	232,000	
Utilities[b]	0	
Subtotal	$ 7,947,000	
Engineering design and inspection at 7 percent of construction costs	556,000	
Subtotal	$ 8,503,000	
		$ 9,000,000
Offsite facilities:		
Paved access road	$ 3,800,000	
Power and telephone lines	496,000	
Water supply system	1,537,000	
Subtotal	$ 5,833,000	

Table 6-3. Cost estimate for an MRS demonstration facility with open-field dry-well storage at the Nevada Test Site (Continued)

Cost category	Amount	Rounded totals
Engineering design and inspection at 25 percent of construction costs	$ 1,458,000	
Subtotal	$ 7,291,000	$ 7,000,000
Subtotal--MRS with open-field dry-well storage		$120,000,000
Contingency at 20 percent		24,000,000
Total--MRS with open-field dry-well storage		$144,000,000

---

[a] Monitoring vehicles included in maintenance and security vehicles.

[b] Open-field dry-well storage utilities included in receiving and packaging utilities.

Table 6-4. Cost estimate for an MRS demonstration facility with tunnel dry-well storage at the Nevada Test Site

Cost category	Amount	Rounded totals
Receiving and packaging (R&P):		
Improvements to land	$ 1,754,000	
R&P building	61,504,000	
Auxiliary buildings	9,888,000	
Miscellaneous structures	1,486,000	
Area and site perimeter instrumentation, communications, and alarm	619,000	
Utilities	5,323,000	
Subtotal	$ 80,574,000	
Engineering design and inspection at 25 percent of construction costs	20,144,000	
Subtotal	$100,718,000	
Canisters	4,100,000	
Subtotal	$104,818,000	
		$105,000,000
Tunnel dry-well storage:		
Access, tunnels, corridors, and storage rooms	$119,400,000	
Surface support facilities	6,850,000	
Maintenance and security vehicles[a]	1,059,000	
Transporter, including shield cask	917,000	
Dry wells, fabrication, and installation	8,380,000	
Area and site perimeter instrumentation, communications, and alarms	436,000	
Underground support systems	5,239,000	
Utilities[b]	0	
Subtotal	$142,281,000	
Engineering design and inspection at 25 percent of construction costs	35,570,000	
Subtotal	$177,851,000	
		$178,000,000
Offsite facilities:		
Paved access road	$ 4,560,000	
Power and telephone lines	697,000	
Water supply system	3,074,000	
Subtotal	$ 8,331,000	

Table 6-4. Cost estimate for an MRS demonstration facility with tunnel dry-well storage at the Nevada Test Site (Continued)

Cost category	Amount	Rounded totals
Engineering design and inspection at 25 percent of construction costs	2,083,000	
Subtotal	$ 10,414,000	$ 10,000,000
Subtotal--MRS with tunnel dry-well storage		$293,000,000
Contingency at 20 percent		59,000,000
Total--MRS with tunnel dry-well storage		$352,000,000

[a] Monitoring vehicles included in maintenance and security vehicles.

[b] Tunnel dry-well storage utilities included in receiving and packaging utilities.

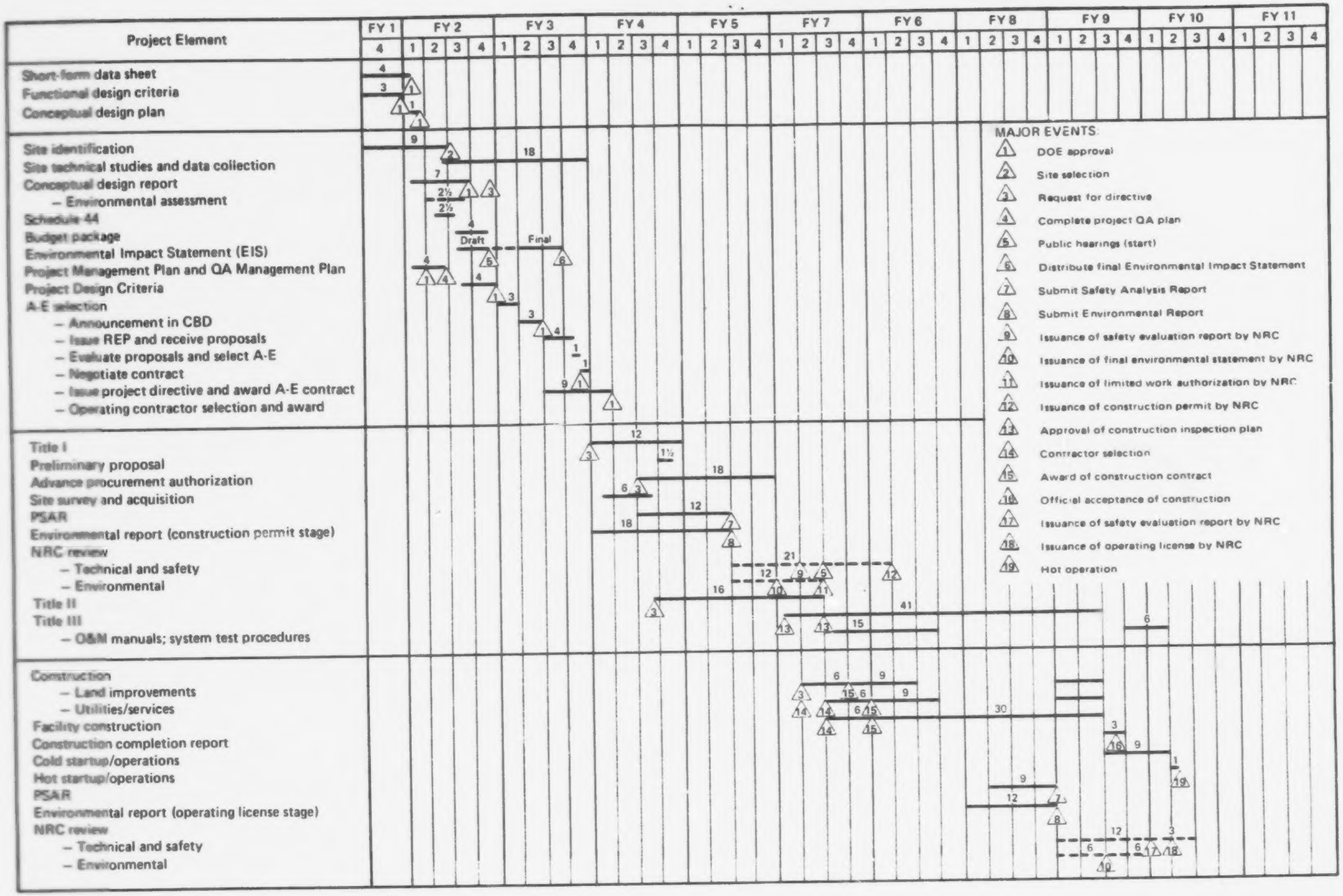


Figure 6-11. Generic schedule for constructing a demonstration facility.

is assumed to be a constant activity on a declining balance of packages in storage. Decommissioning would begin when all packages in the storage area are removed and would continue for about 2 years after the last storage area is vacated and the packages shipped offsite.

[redacted]

References for Chapter 6

General Atomic Company. 1981. Monitored Retrievable Storage Concept Definition and Evaluation Report. GA-A16424, San Diego, Calif.

Rockwell Hanford Operations. 1978. Spent Fuel Receiving and Packaging Facility - Conceptual Design Report. CDR-RHO-CD-506, Richland, Wash.

Rockwell Hanford Operations. 1979. Dry-Well Storage Facility Conceptual Design Study. Report No. 79-8-R, Richland, Wash.

Rockwell Hanford Operations. 1981. Monitored Retrievable Storage Demonstration Facility and Dry-Well Storage Field - Conceptual Design Study. Basalt Waste Isolation Project, RHO-BWI-C-118, Richland, Wash.

Westinghouse Electric Corporation. 1981. Conceptual Design Evaluation Study for Interim Off-Site Spent Fuel Storage Installation. WI 81-176, Pittsburgh, Penn.

☆U.S. GOVERNMENT PRINTING OFFICE: 1981 — 361-076 3047